

Mechanical Properties of Nanostructured Materials

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Introduction

Mechanical properties of nanostructured materials can be difficult to measure, especially for thin films. Nanoindentation offers a useful probe, but separating the layer properties from those of the substrate in the data is difficult for normal analytical methods. Another analysis tool was needed.

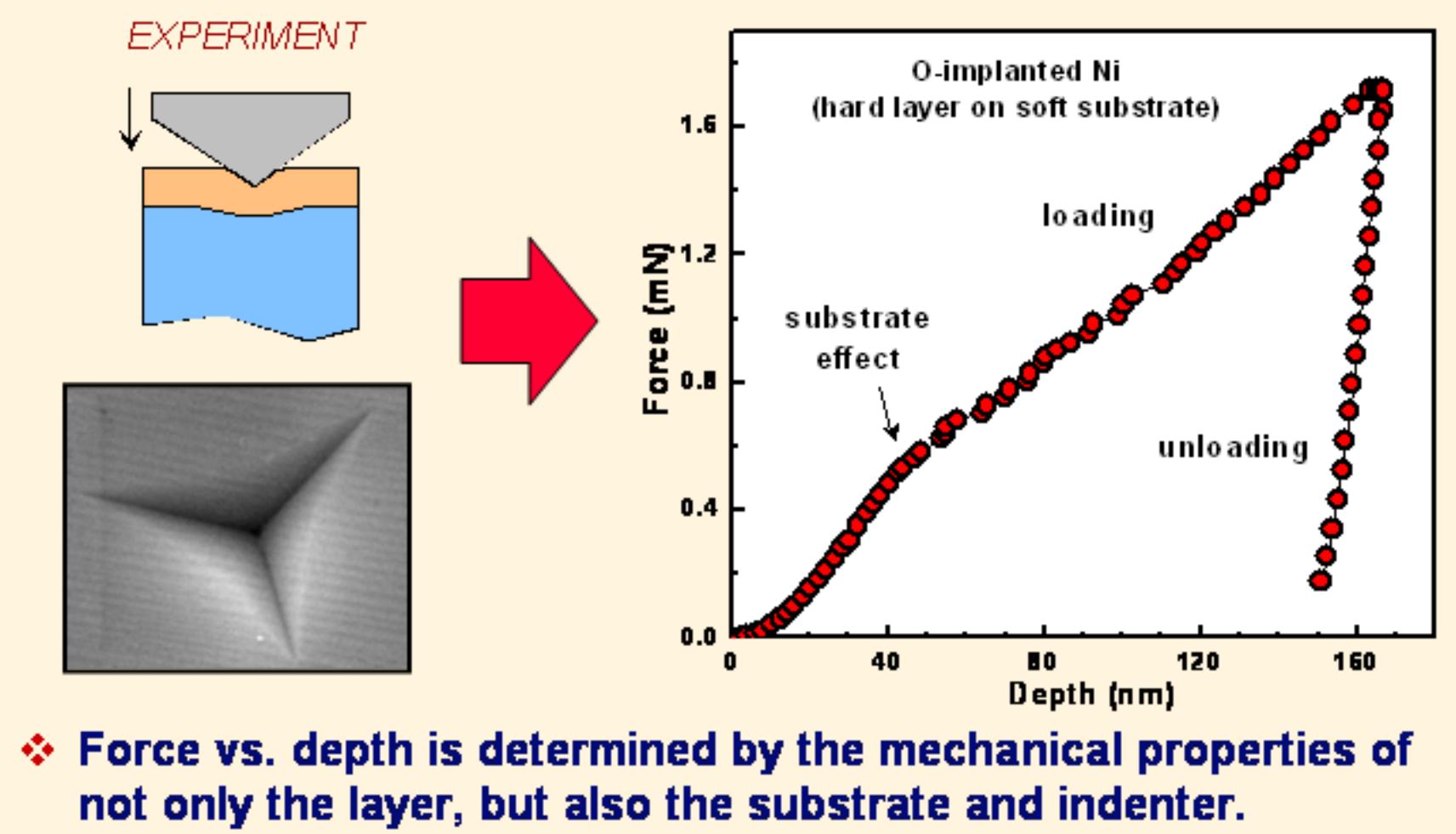
We have developed such a tool for measuring mechanical properties of thin films:

- Nanoindentation is combined with finite-element modeling. The modeling enables the separation of film properties from the underlying substrate materials. No other method exists for detailed *in-situ* quantification of these properties in thin films.

Here we describe the technique and illustrate it with results from very fine-grained Ni films:

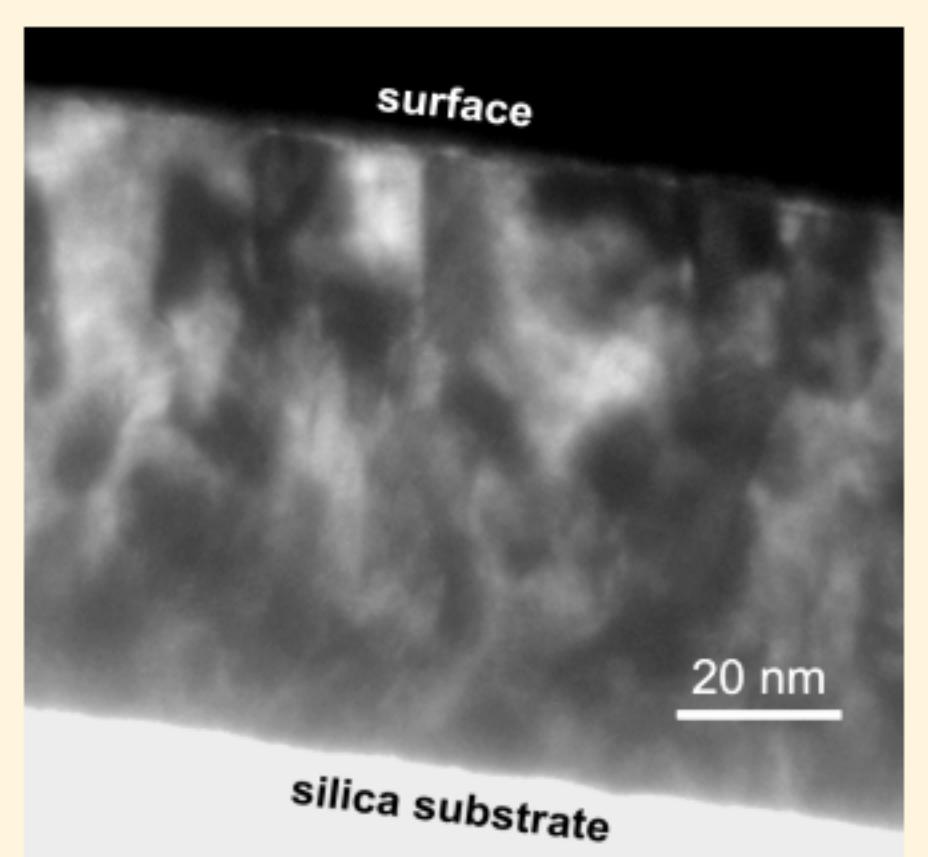
- Ni films formed by pulsed laser deposition (PLD).
- Nanoindentation / modeling shows Hall-Petch scaling of the hardness down to ~10 nm grains.
- In-situ* TEM straining confirms dislocation motion in these films.

Nanoindentation of thin films

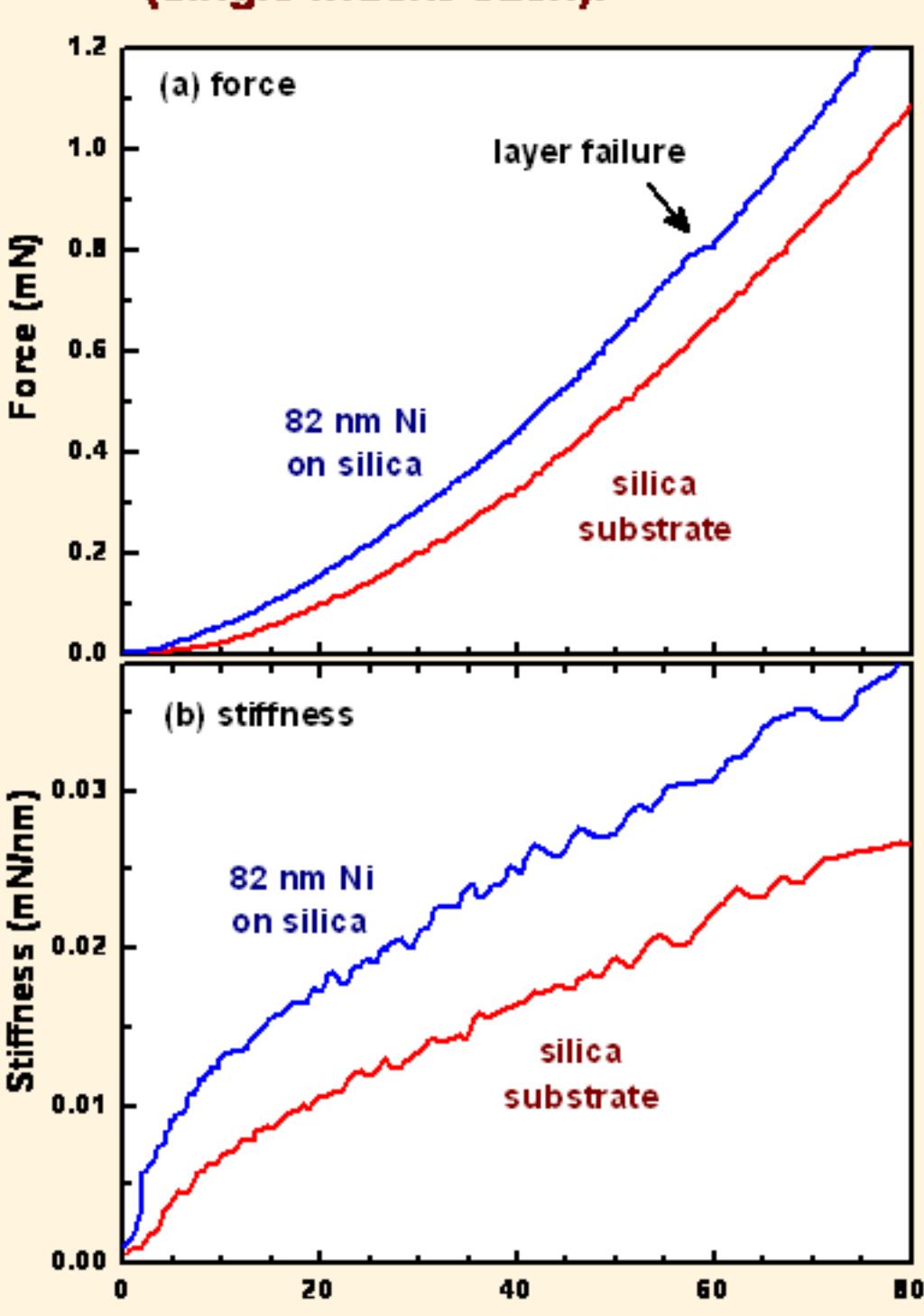


Example: 82 nm PLD Ni film on silica

XTEM of layer shows Ni grains 12.3 ± 4.4 nm in diameter.

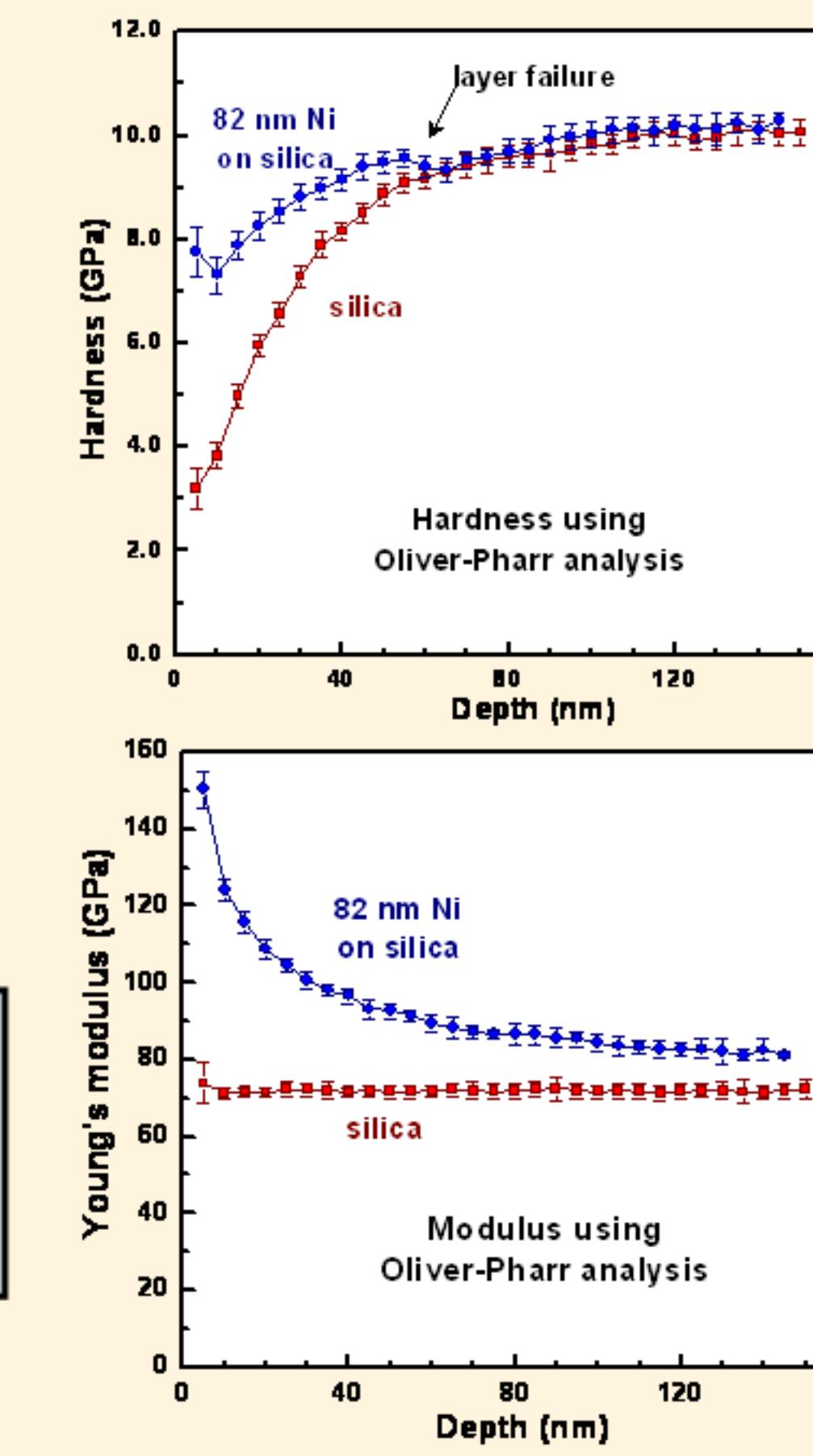


Nanoindentation CSM data (single indent each).

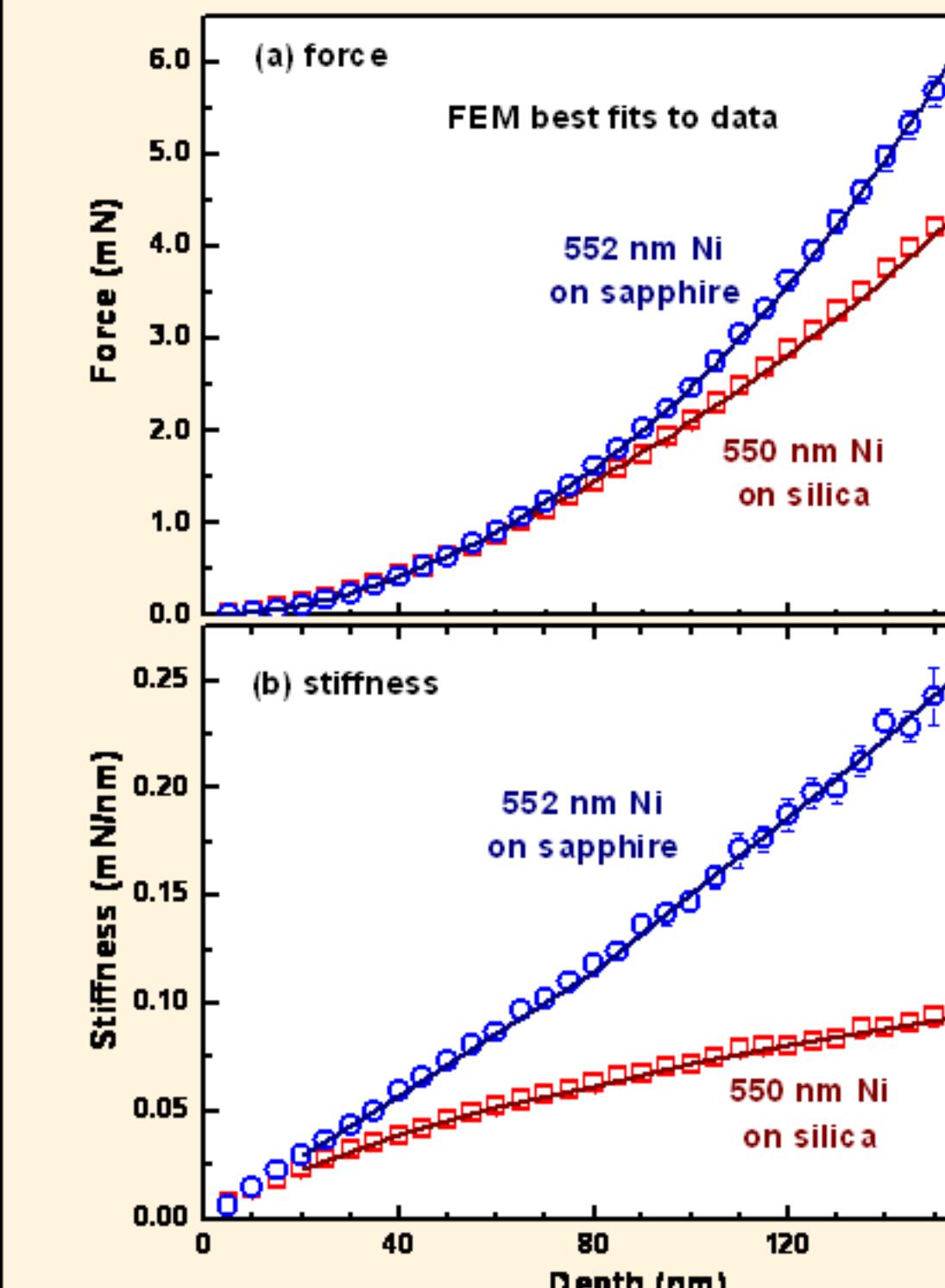


Analytical Oliver-Pharr analysis

Standard analytical methods for extracting H and E unable to determine properties for such a thin layer.



Example: PLD Ni layers on different substrates

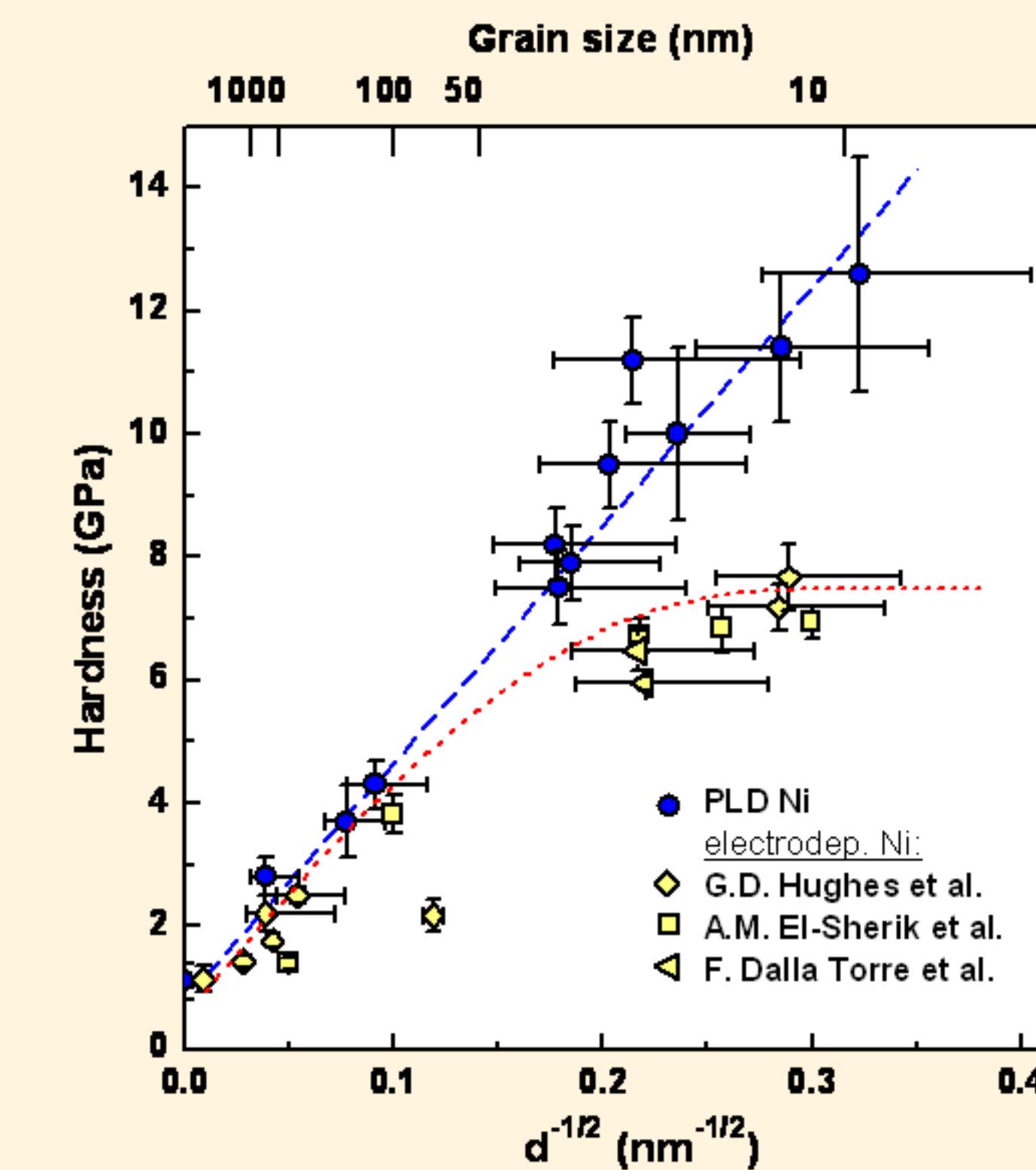


PLD Ni layers on very different substrates, showing how the FEM modeling can account for each. Grain sizes are from TEM.

PLD Ni layer on sapphire:
Grain size: 31.8 ± 13.7 nm
Y: 2.94 ± 0.23 GPa
E: 212 ± 13 GPa
H: 8.2 ± 0.6 GPa

PLD Ni layer on silica:
Grain size: 21.8 ± 10.3 nm
Y: 4.13 ± 0.2 GPa
E: 239 ± 16 GPa
H: 11.2 ± 0.7 GPa

Hall-Petch scaling in PLD Ni: summary



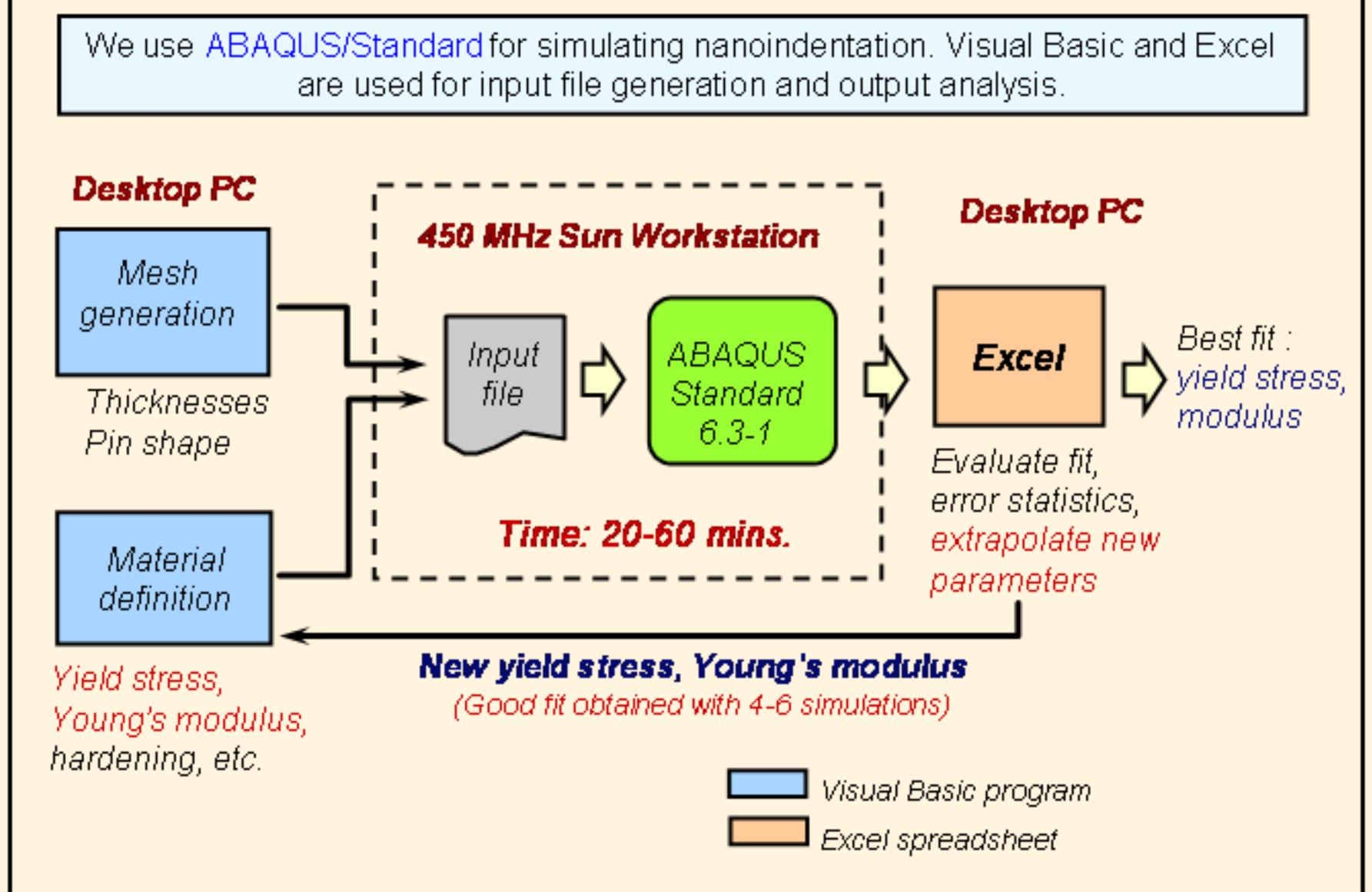
Hall-Petch scaling:
 $H = H_0 + Kd^{-1/2}$
where d is the grain diameter and H_0 and K are constants.

(1) E.O. Hall, Phys. Soc. of London B64, 747 (1951).
(2) N.M. Petch, J. Iron Steel Inst. 174, 25 (1953).

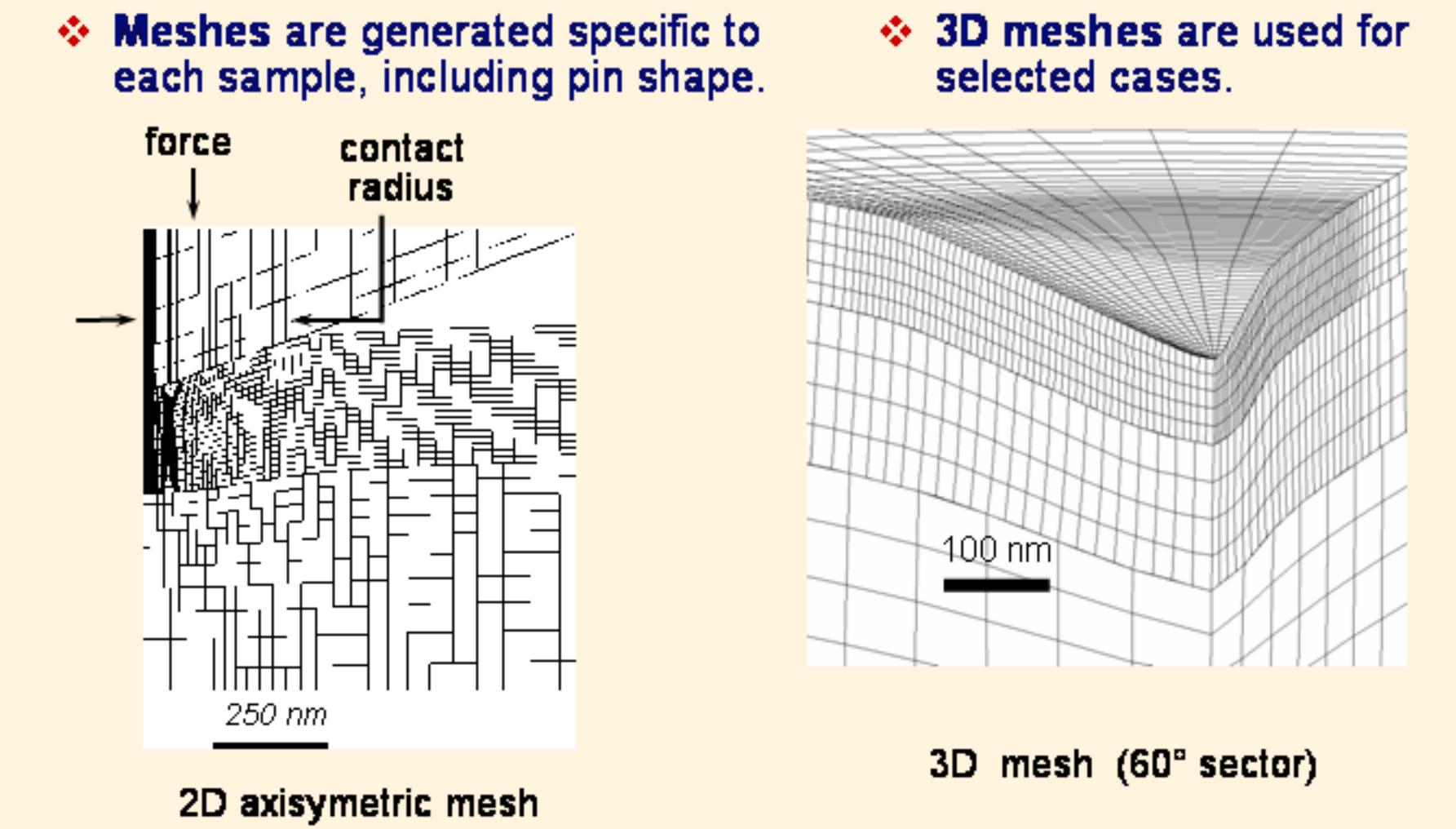
Electrodeposited Ni:
(3) G.D. Hughes, et al, Scr. Met. 20, 93 (1986).
(4) A.M. El-Sherik, et al, Scr. Metall. Mater. 27, 1185 (1992).
(5) F. Dalla Torre, et al, Acta Mat. 50, 3957 (2002).

Atomistic simulations:
(6) H. Van Swygenhoven, et al, Scr. Mat. 44, 1513 (2001).

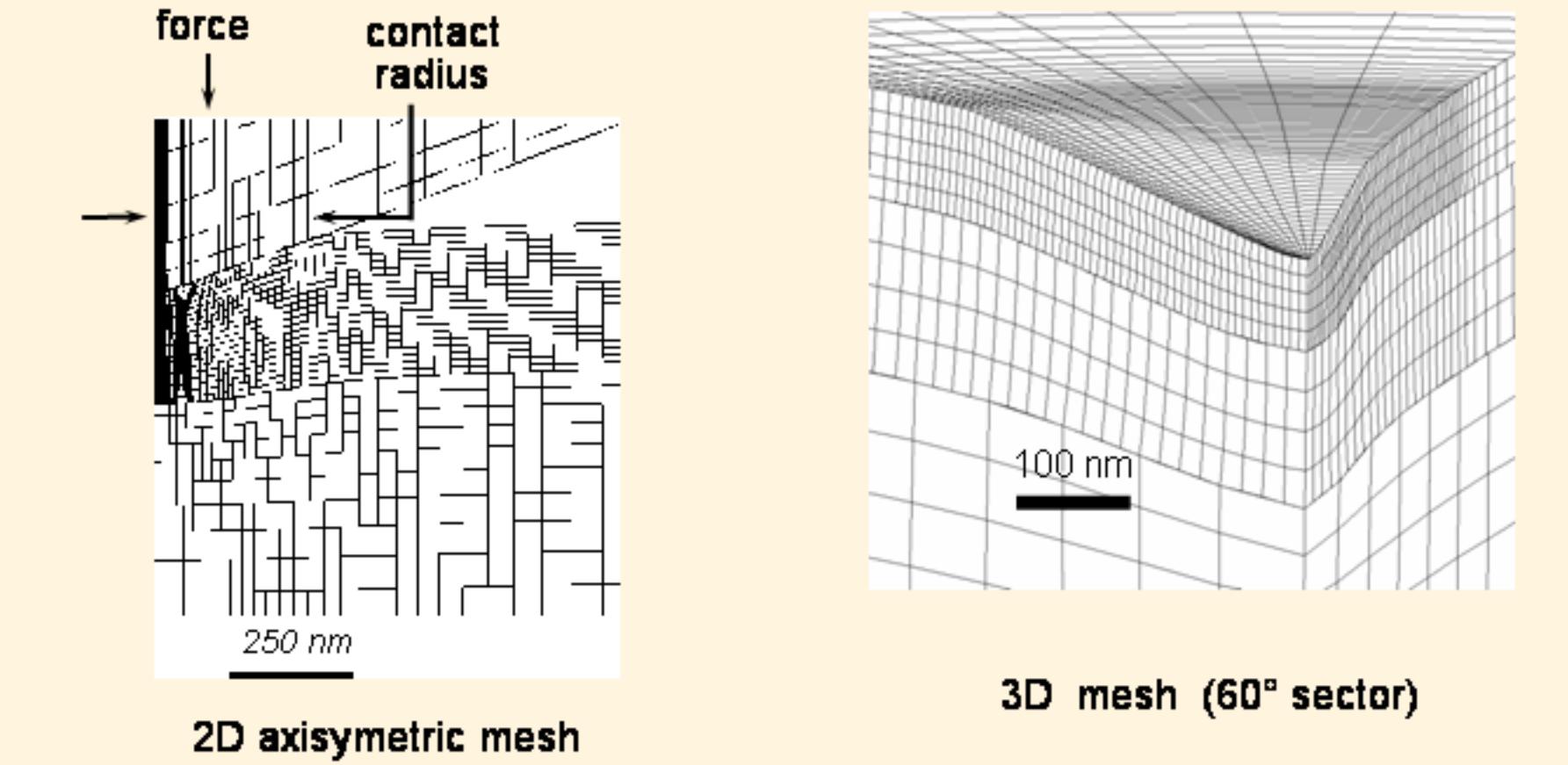
Finite-element modeling of nanoindentation



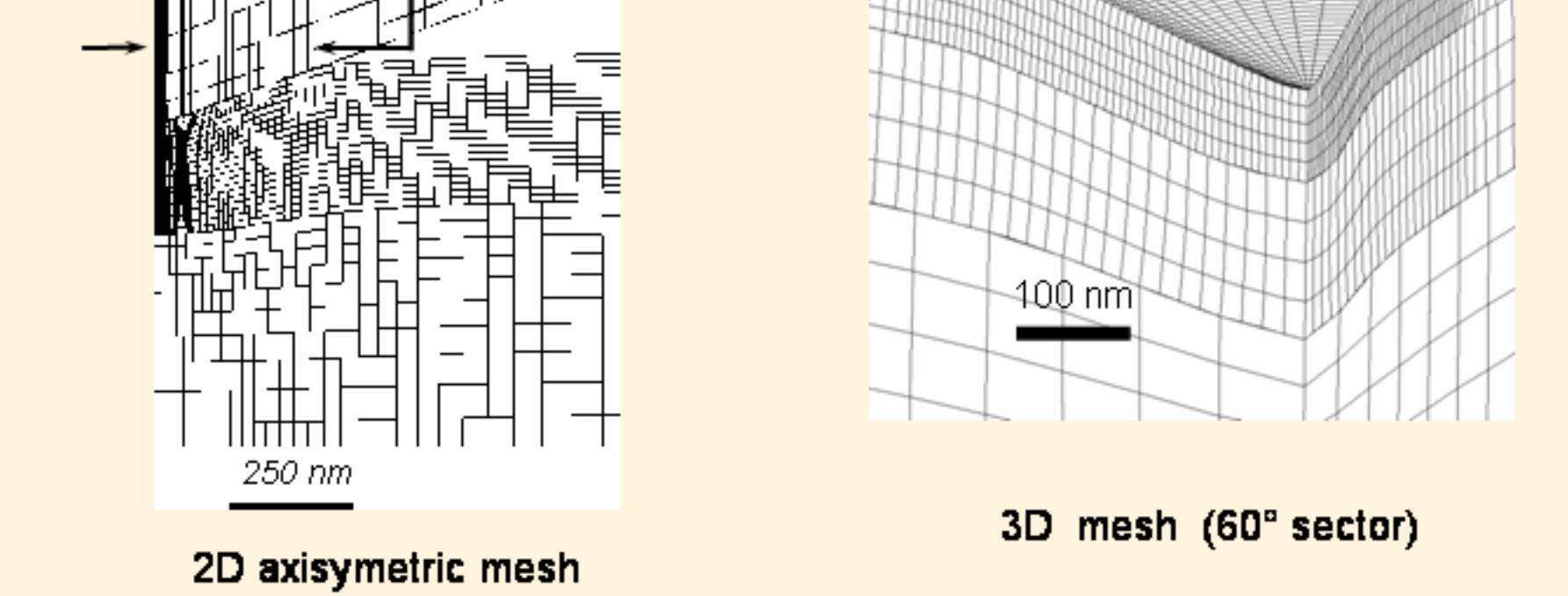
Finite element meshes



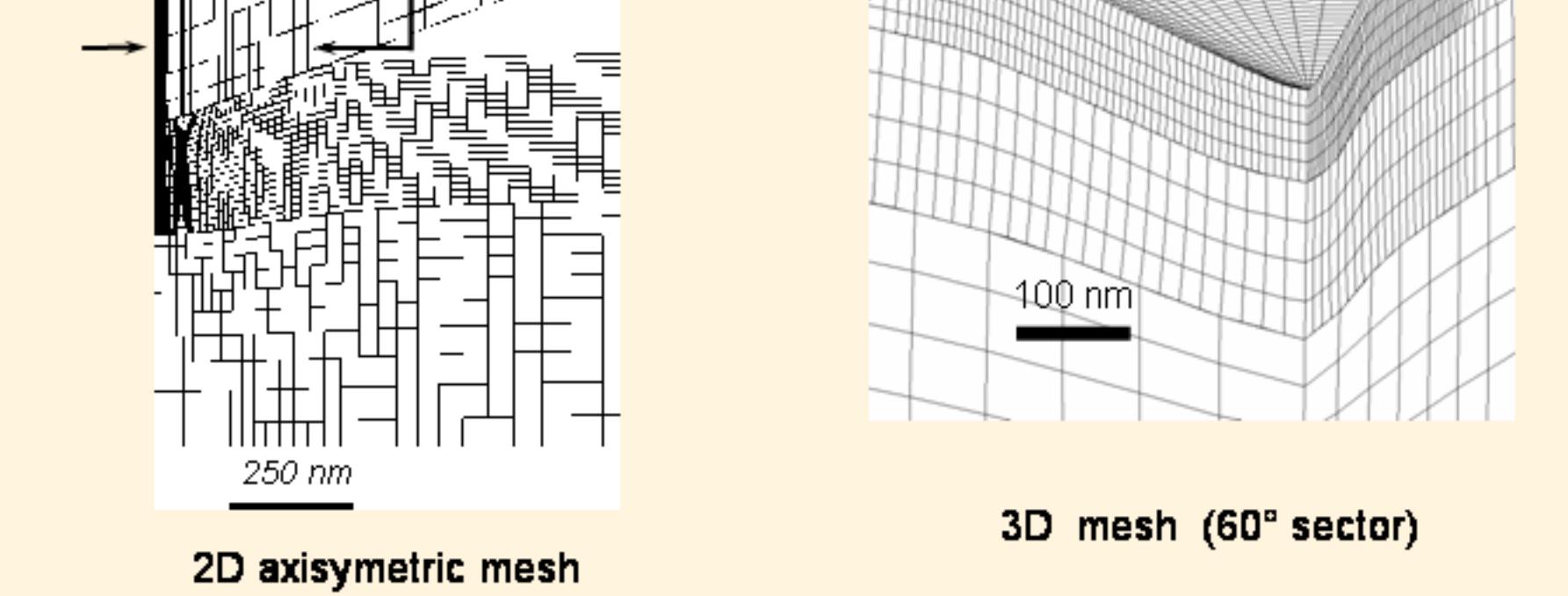
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- 3D meshes are used for selected cases.



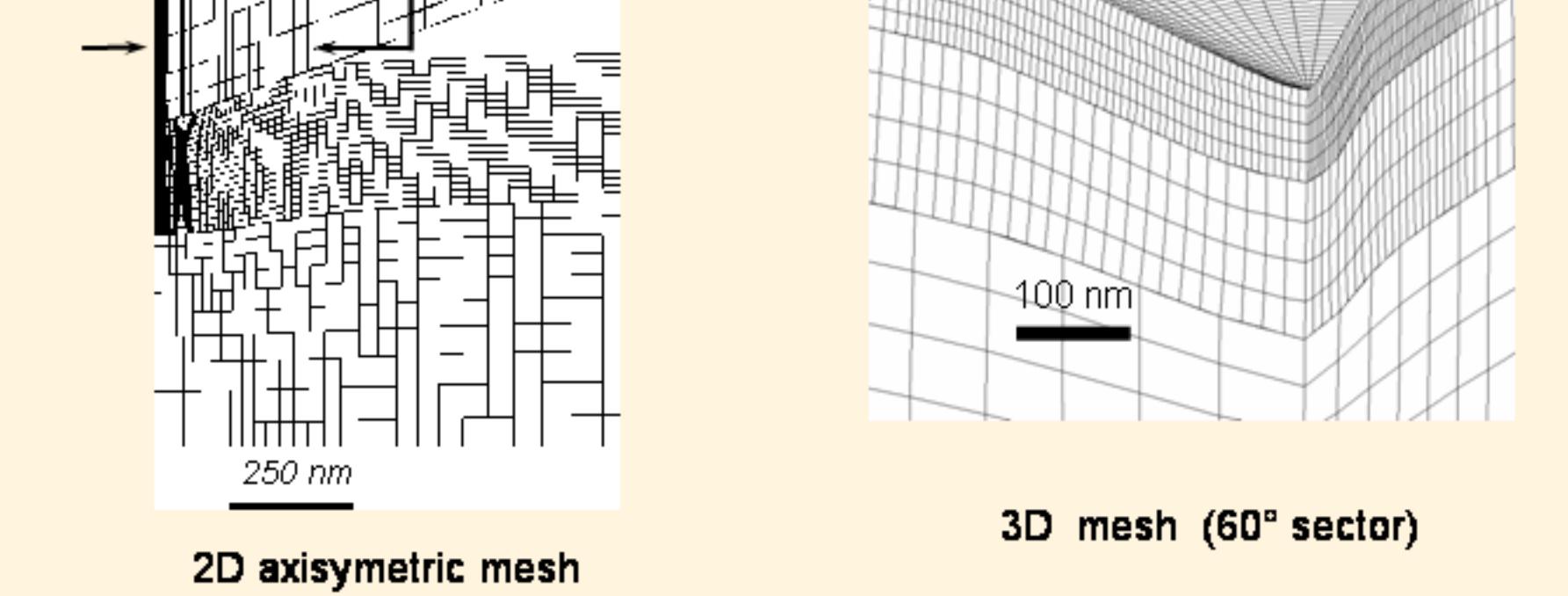
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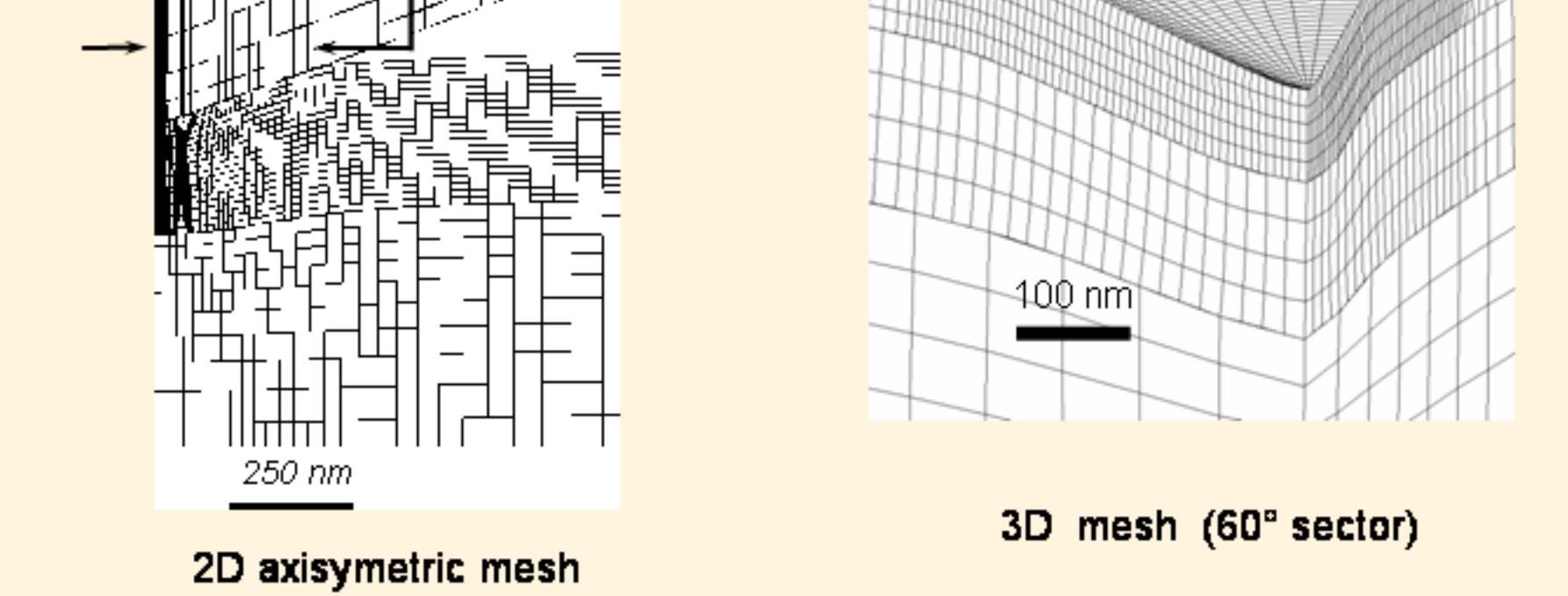
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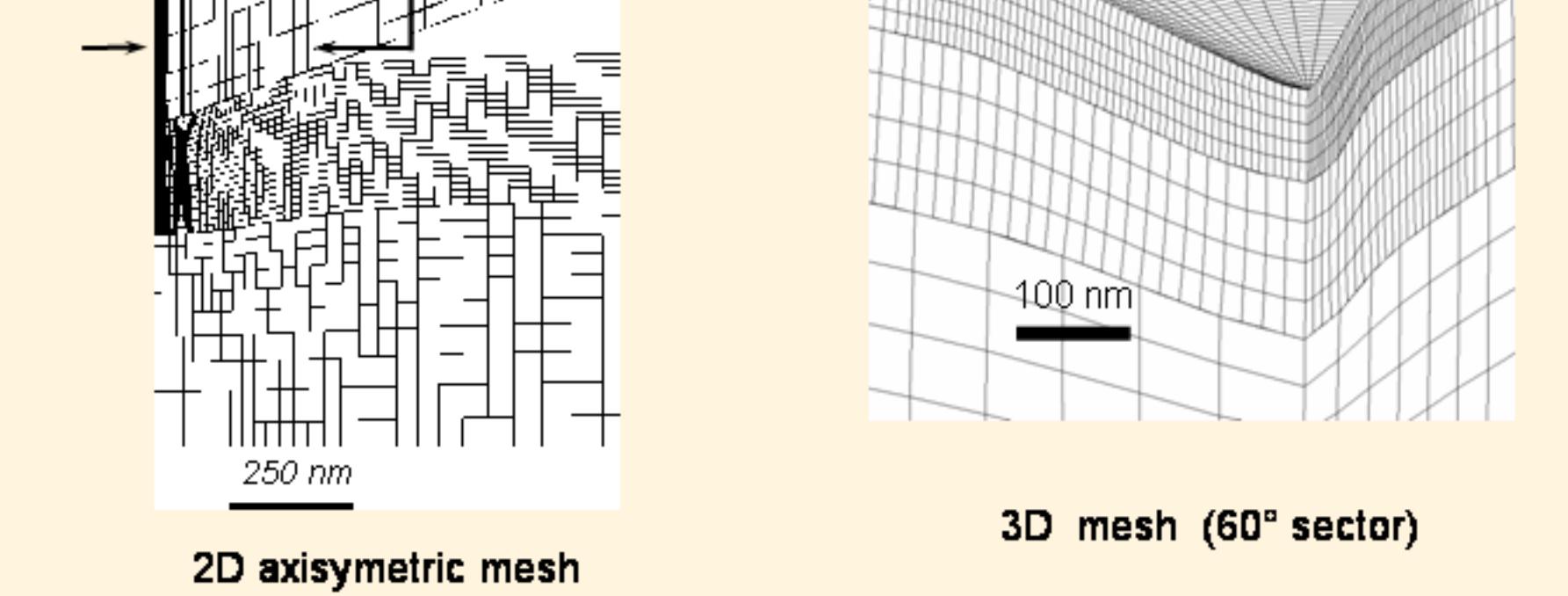
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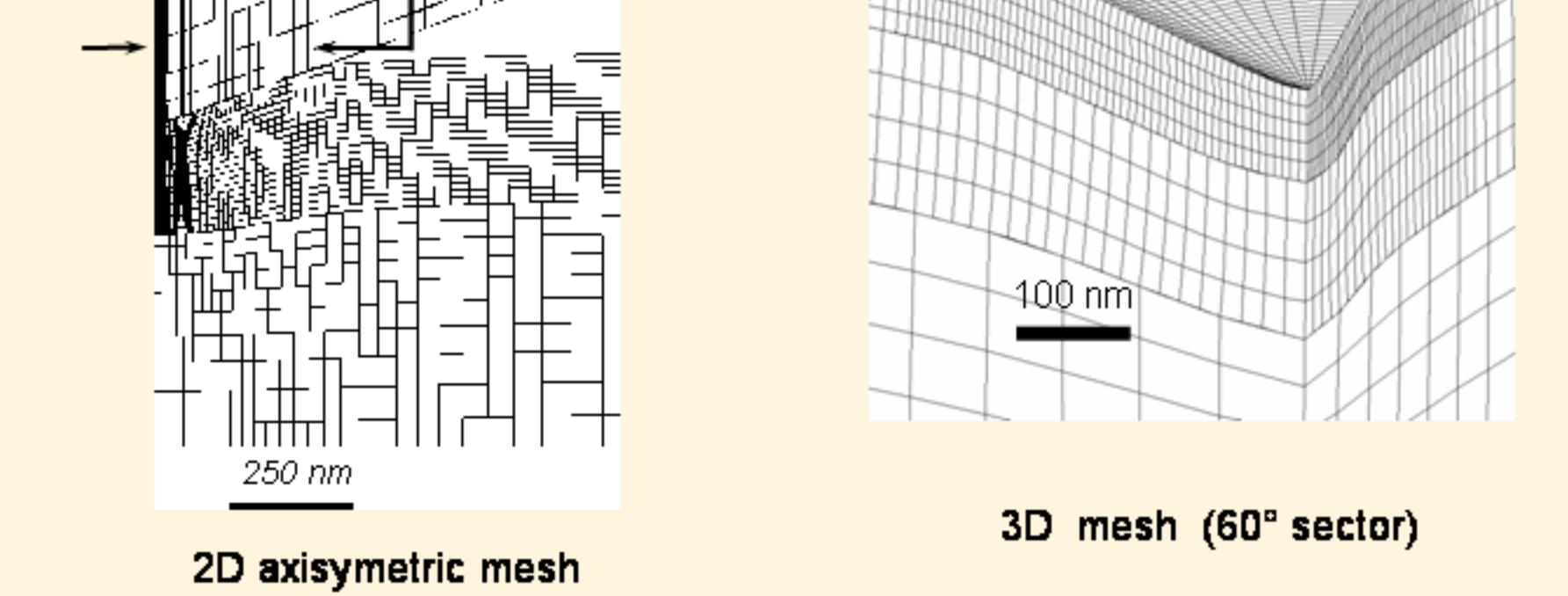
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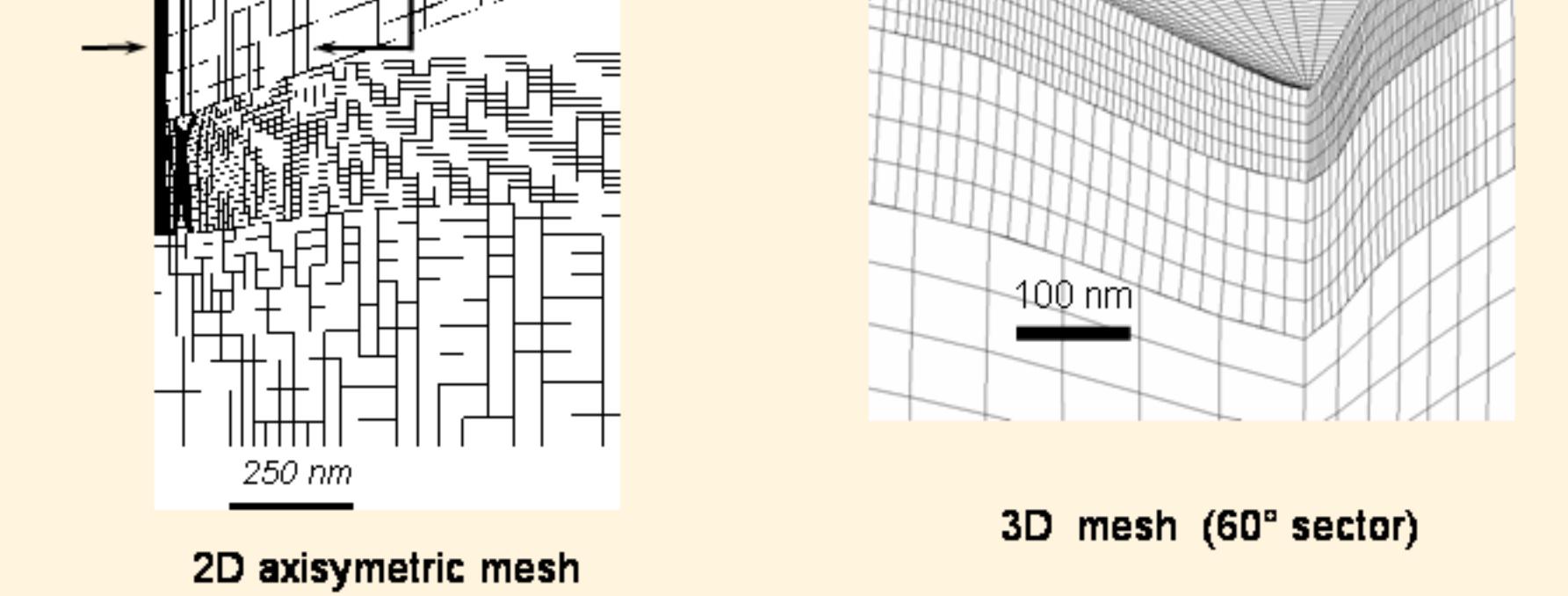
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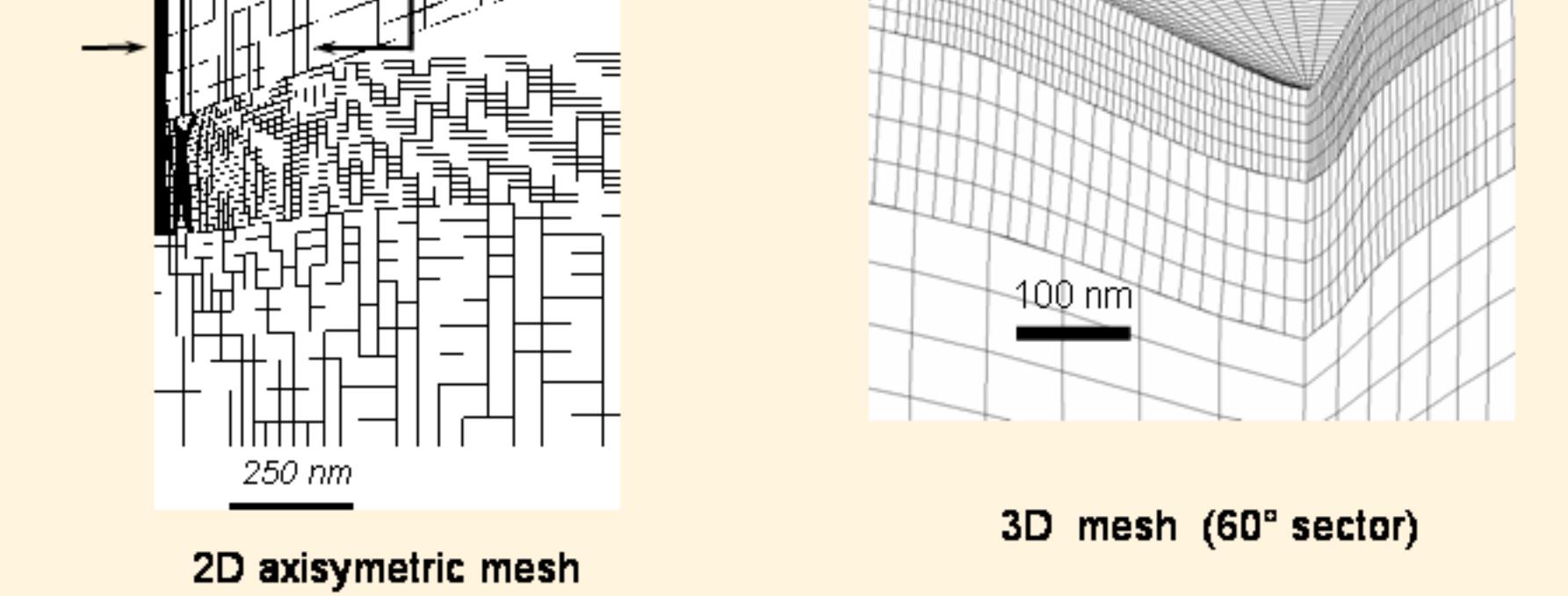
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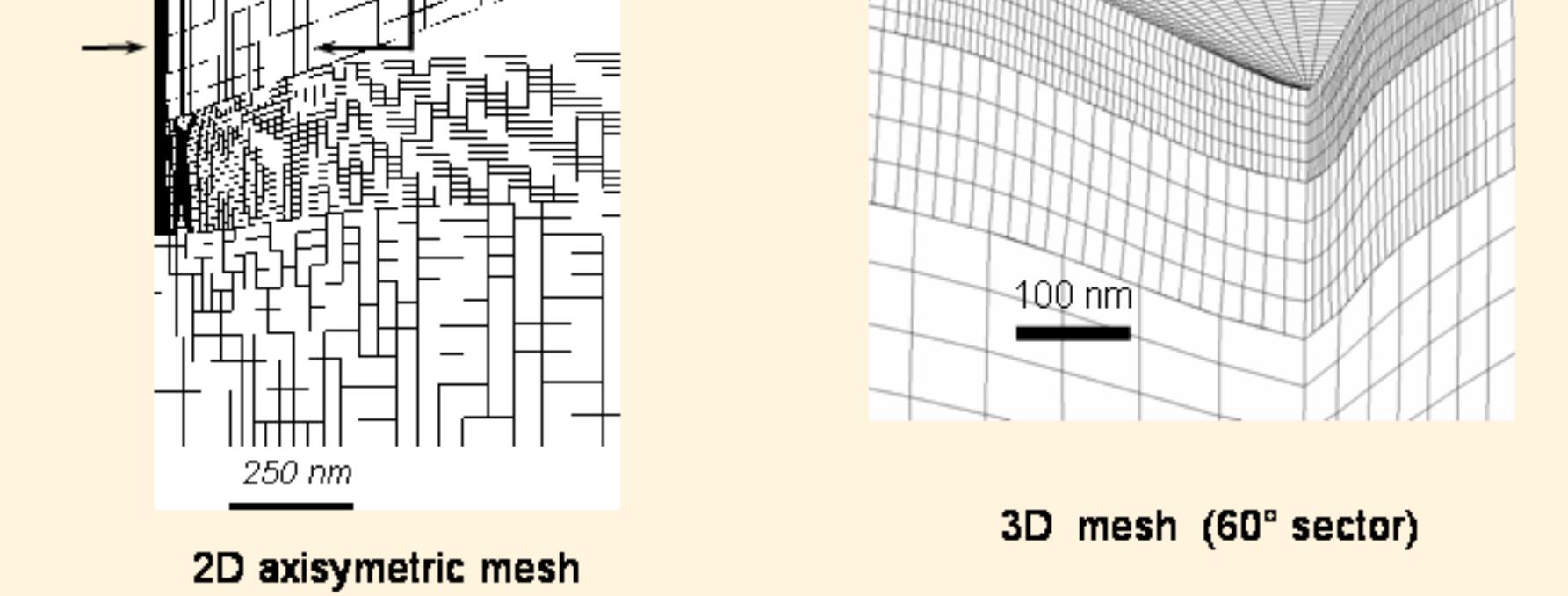
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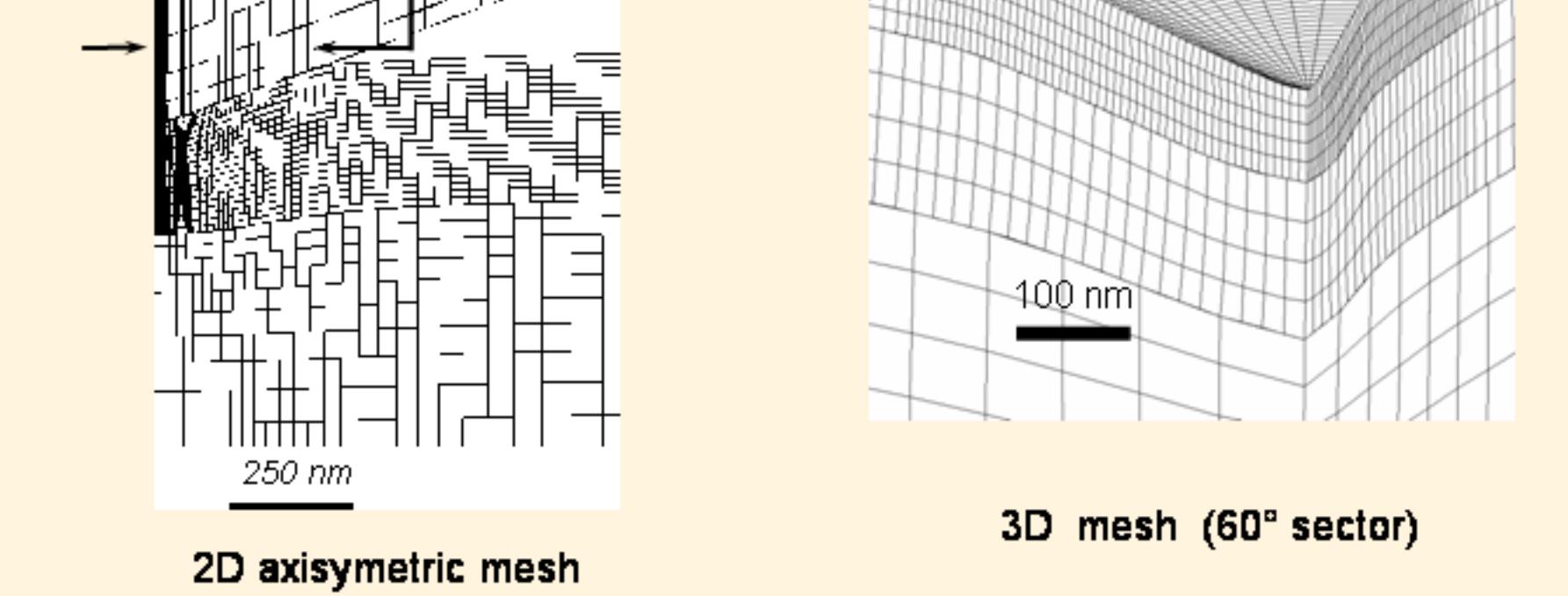
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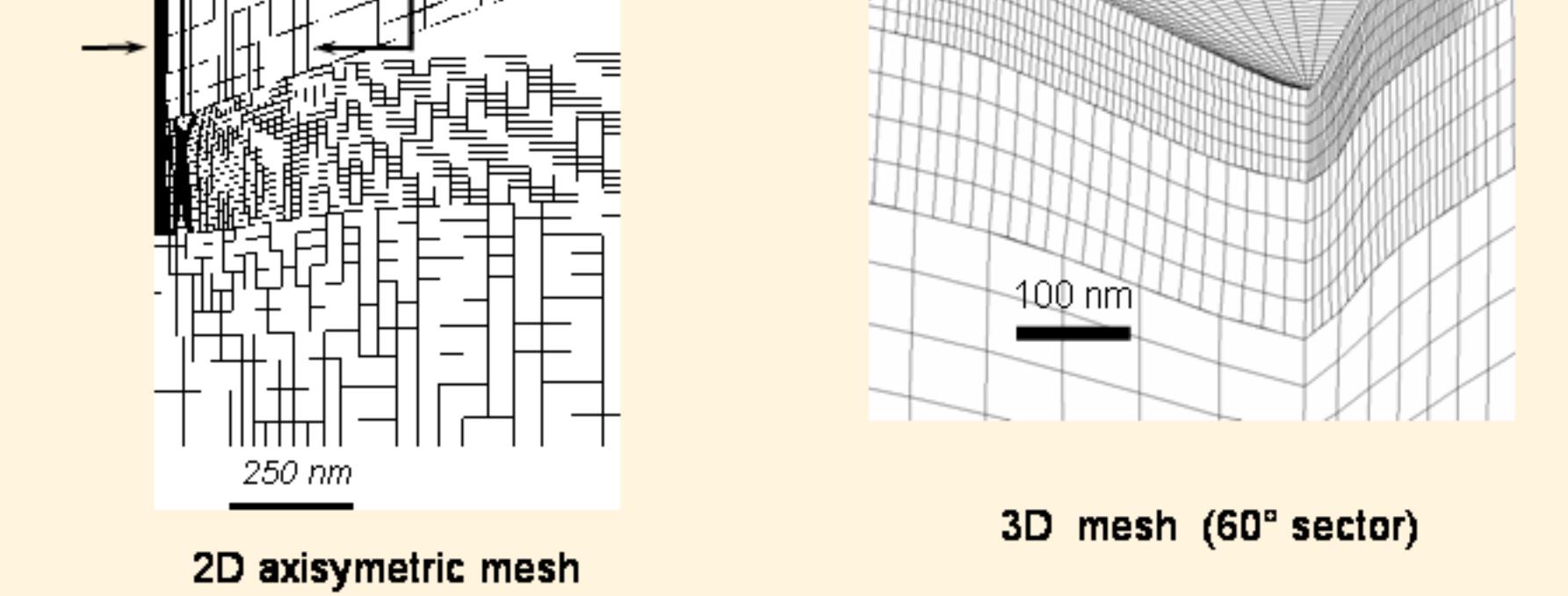
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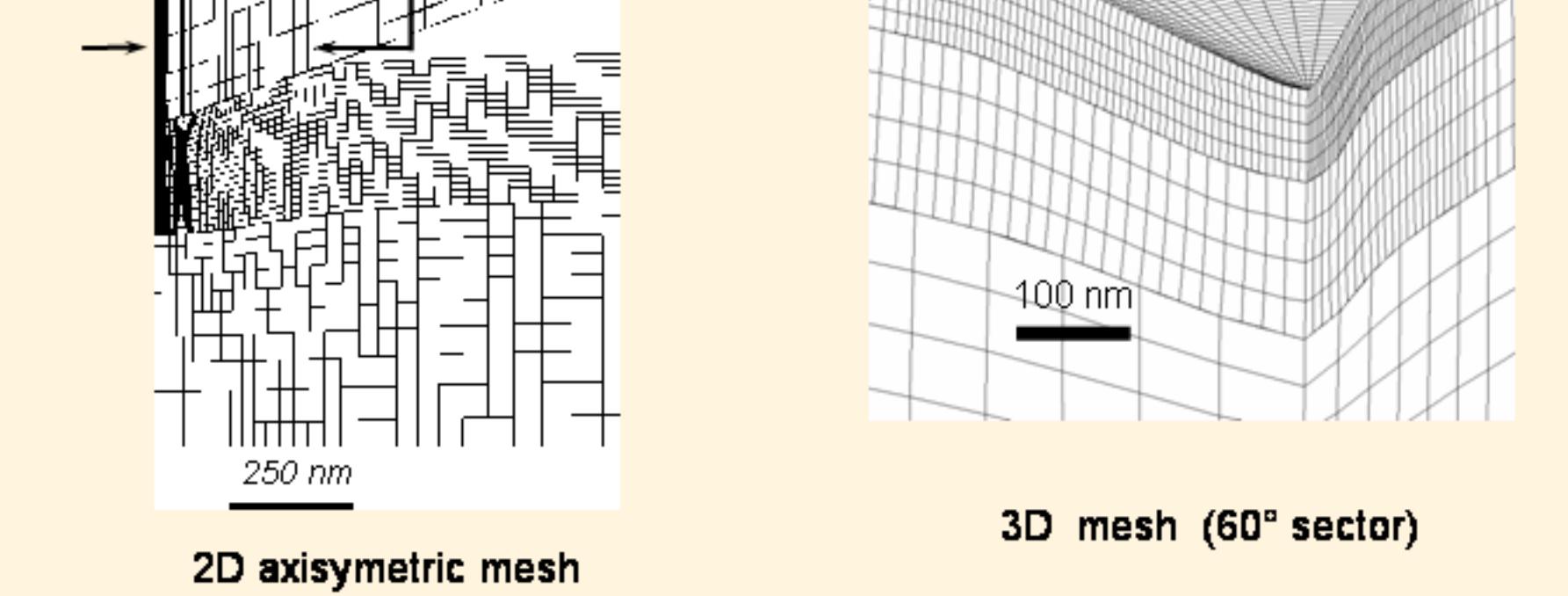
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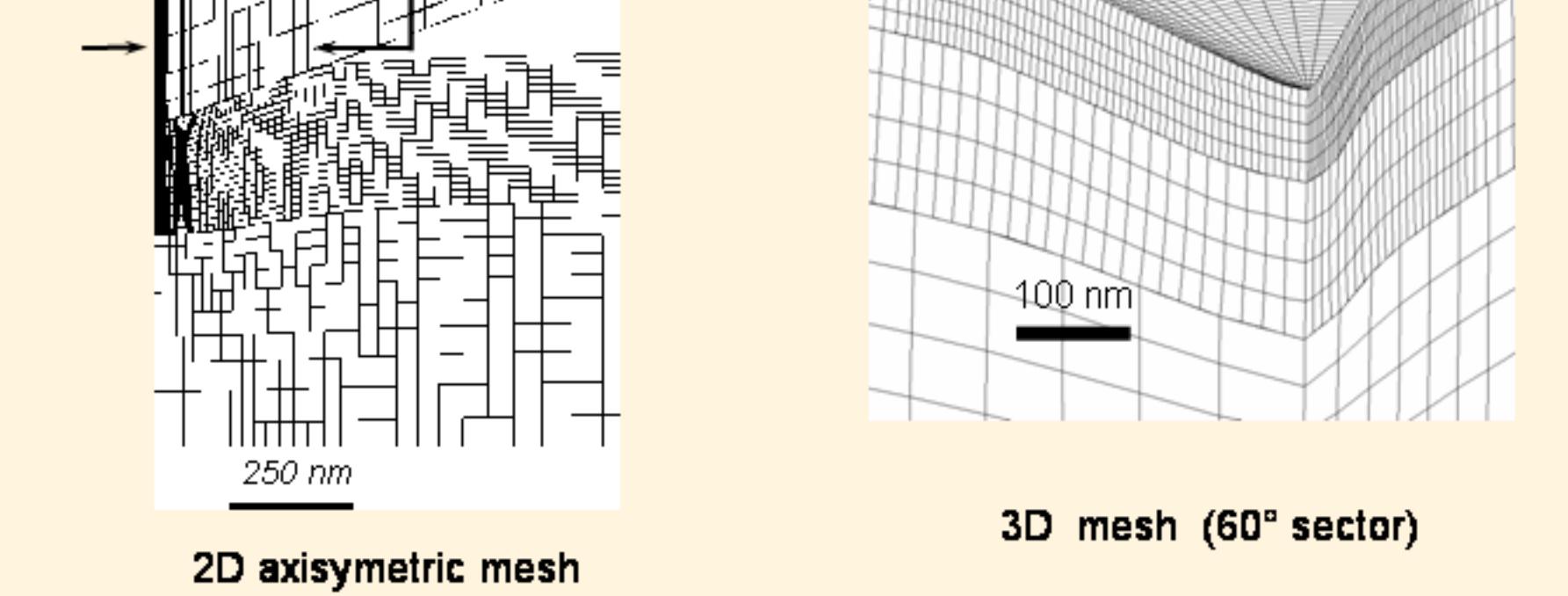
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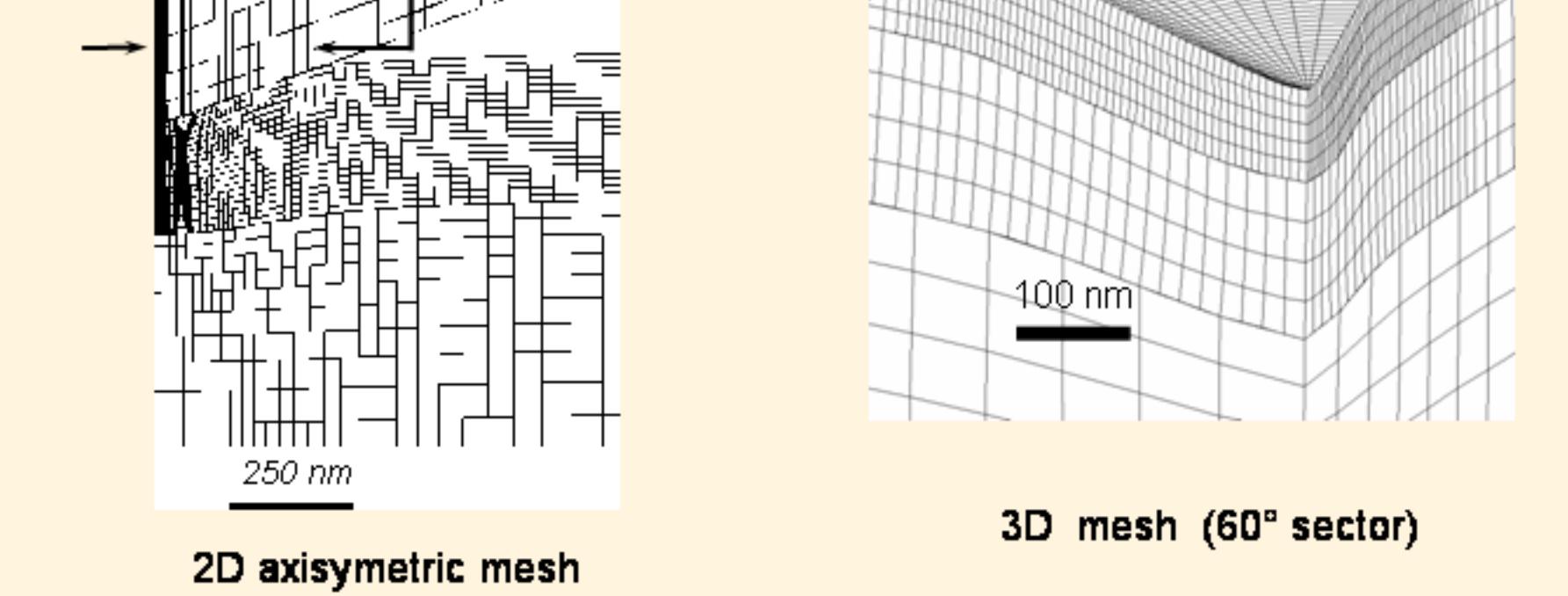
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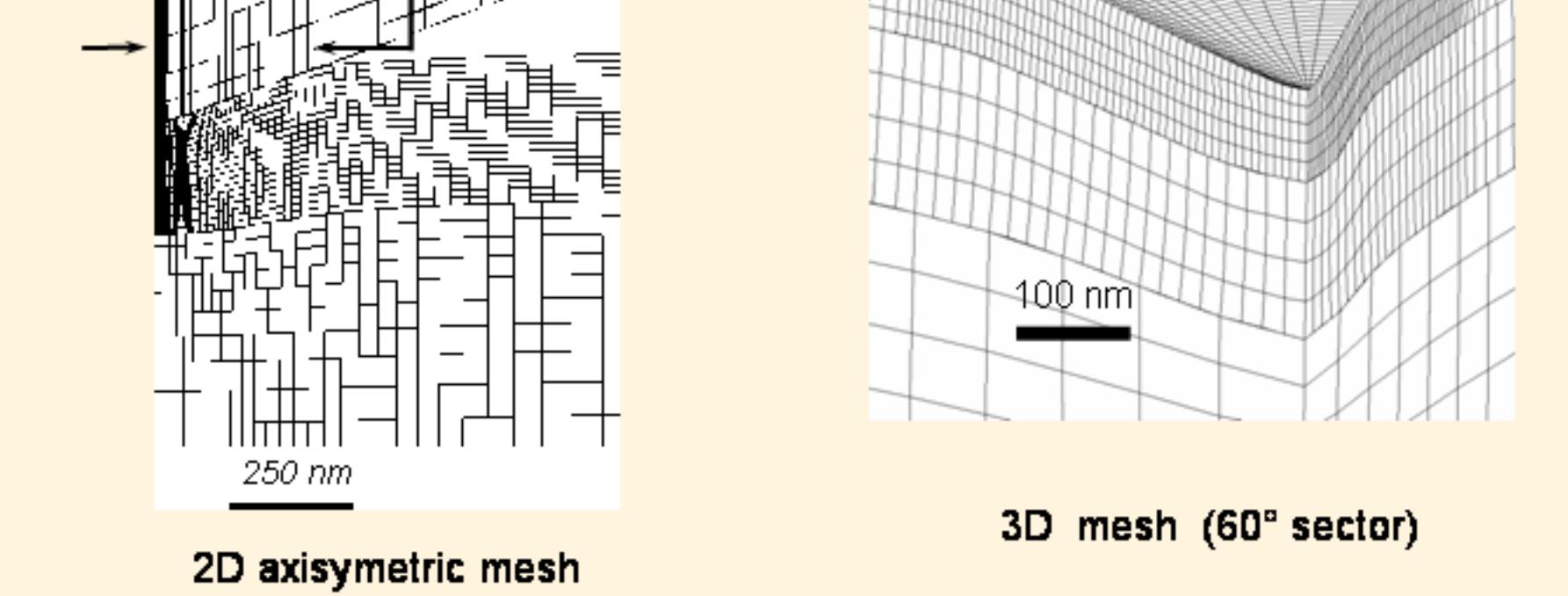
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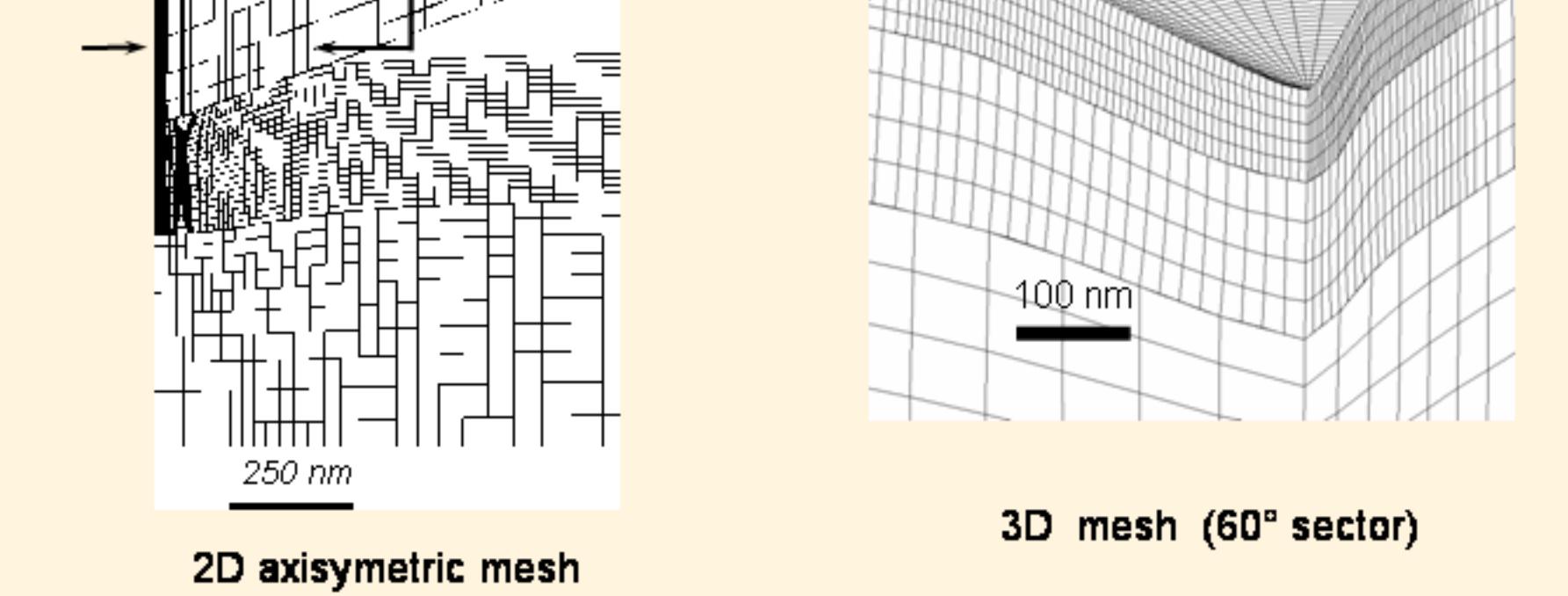
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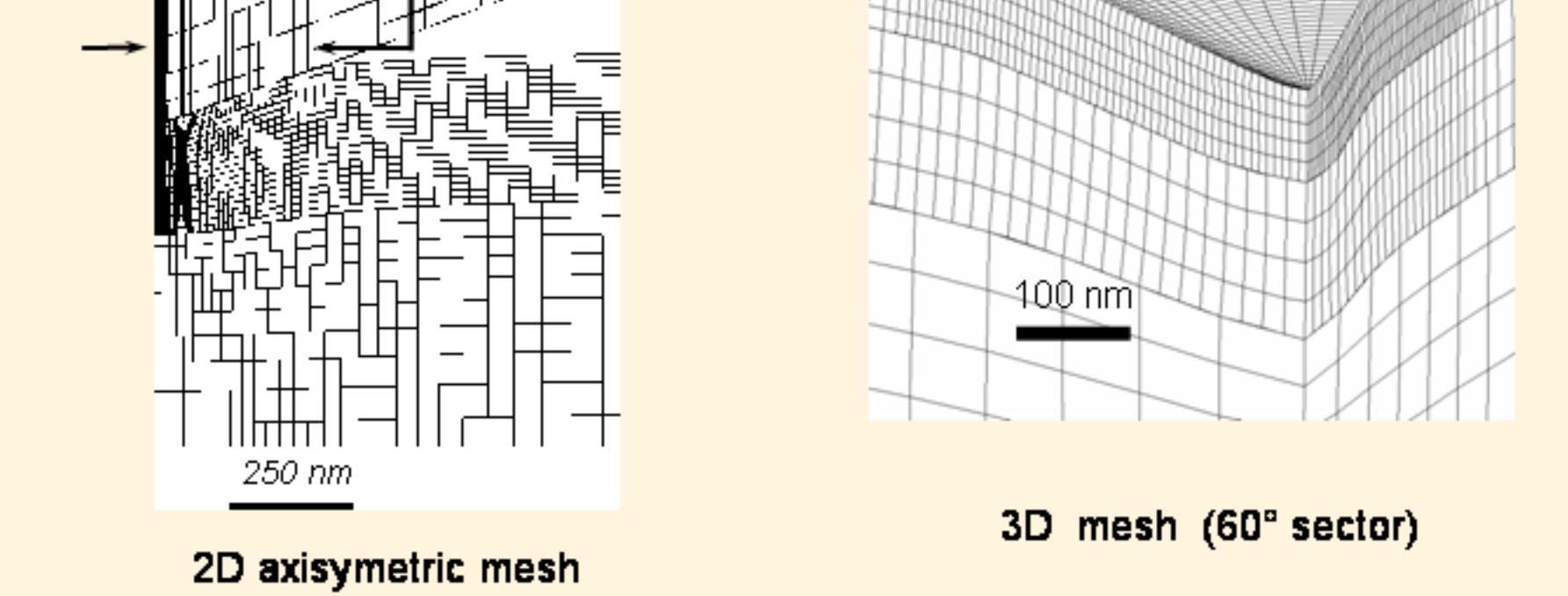
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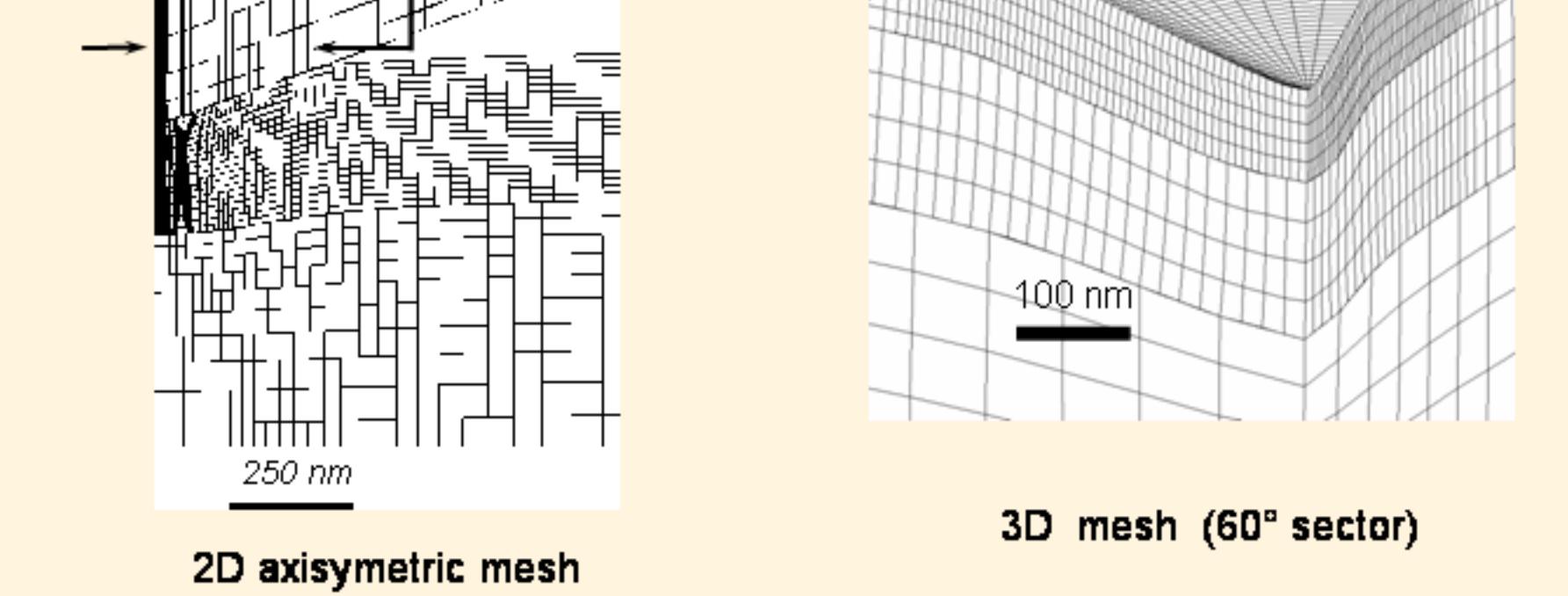
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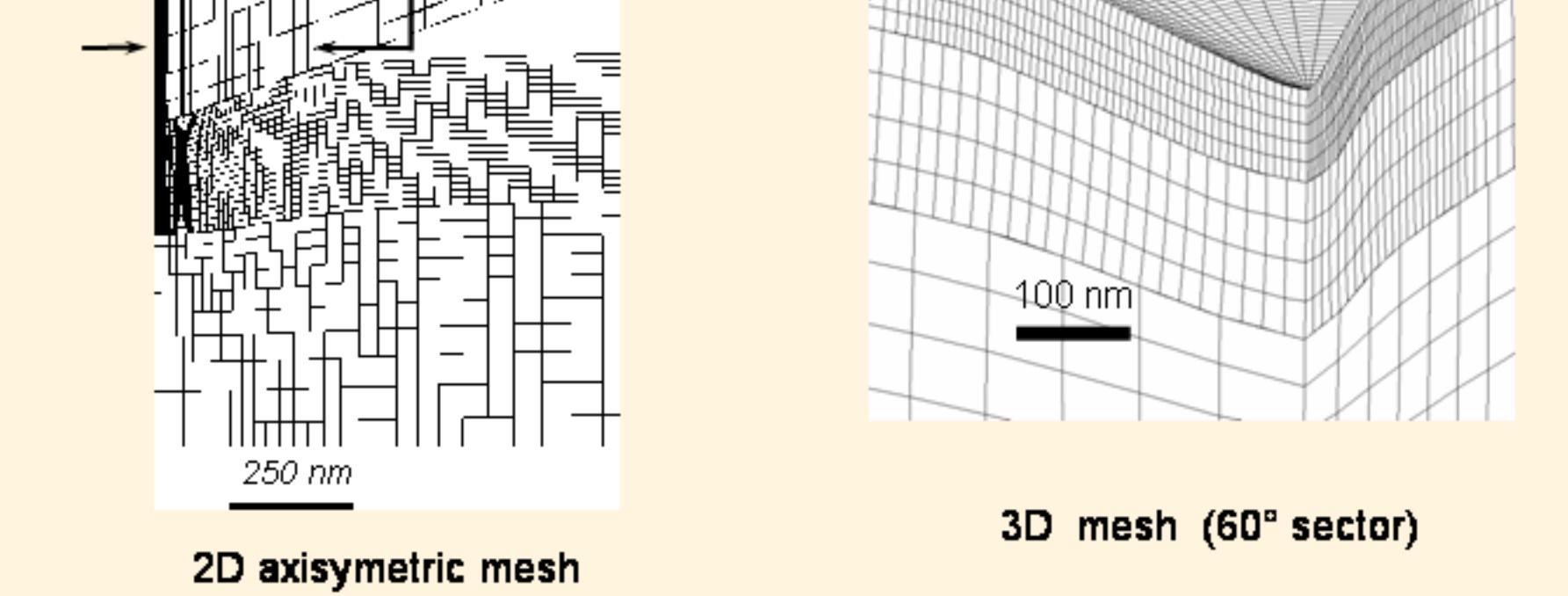
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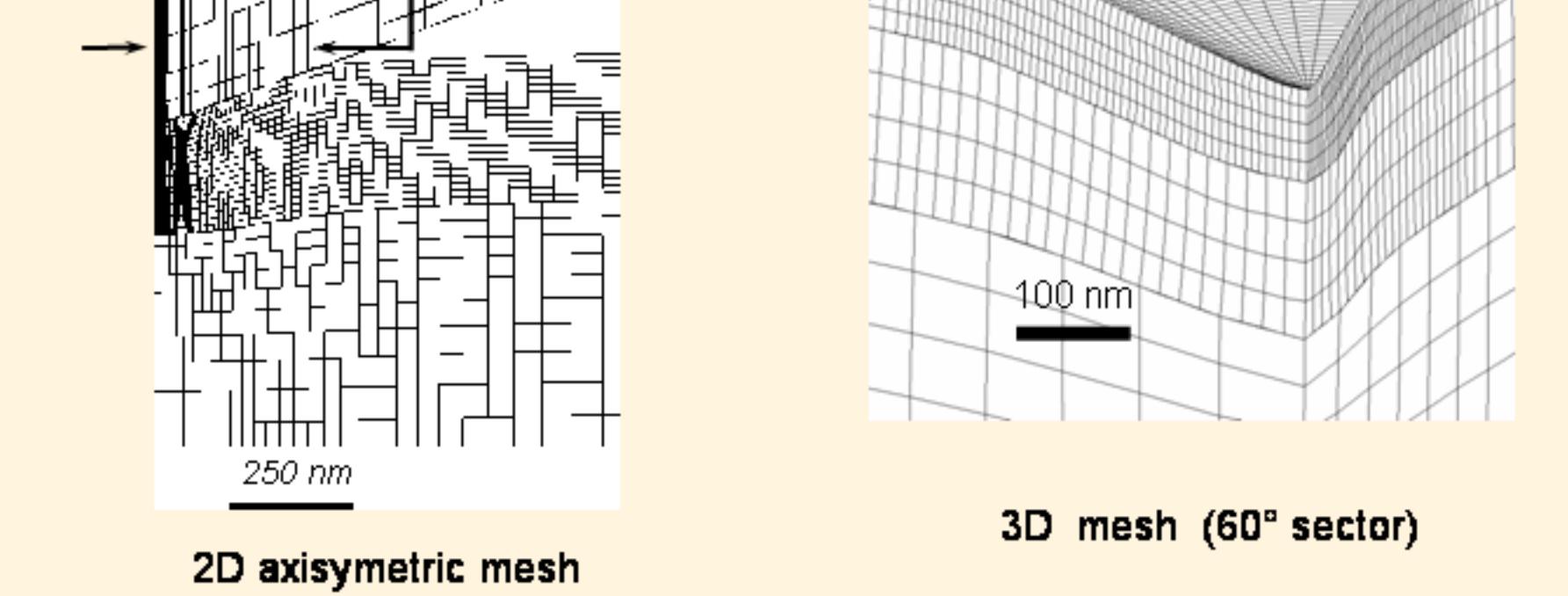
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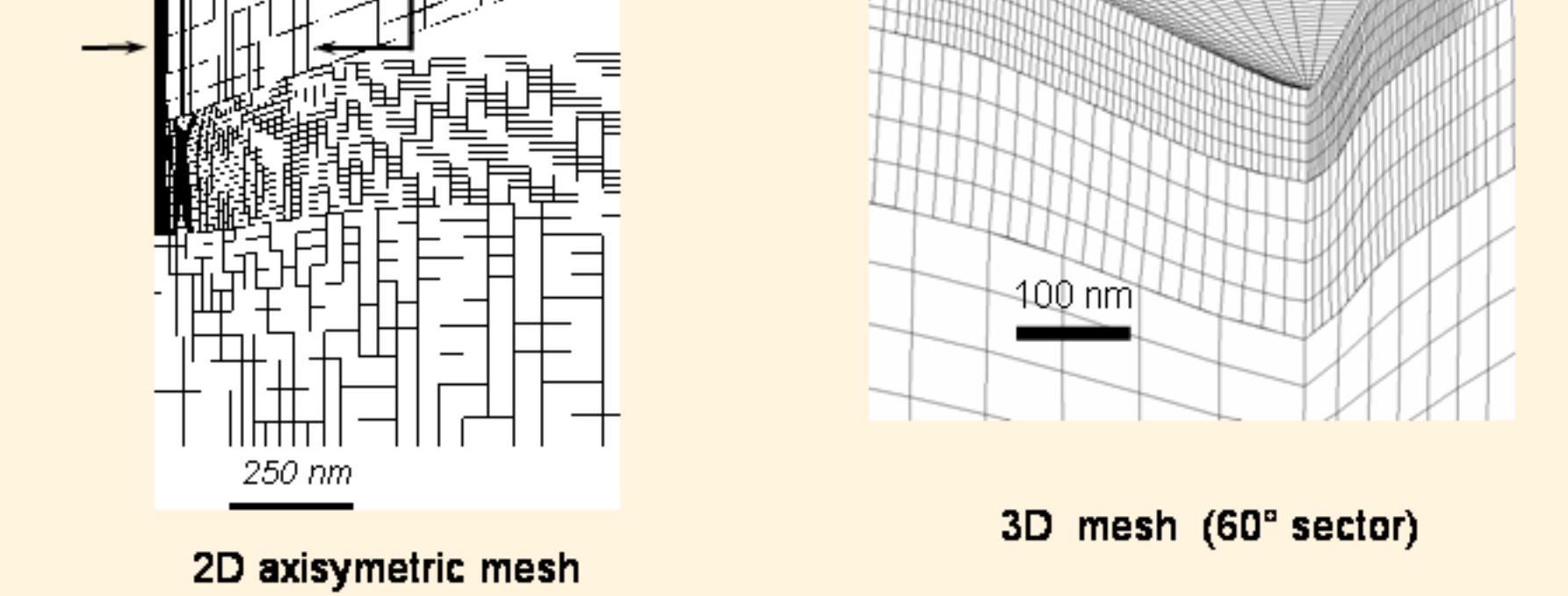
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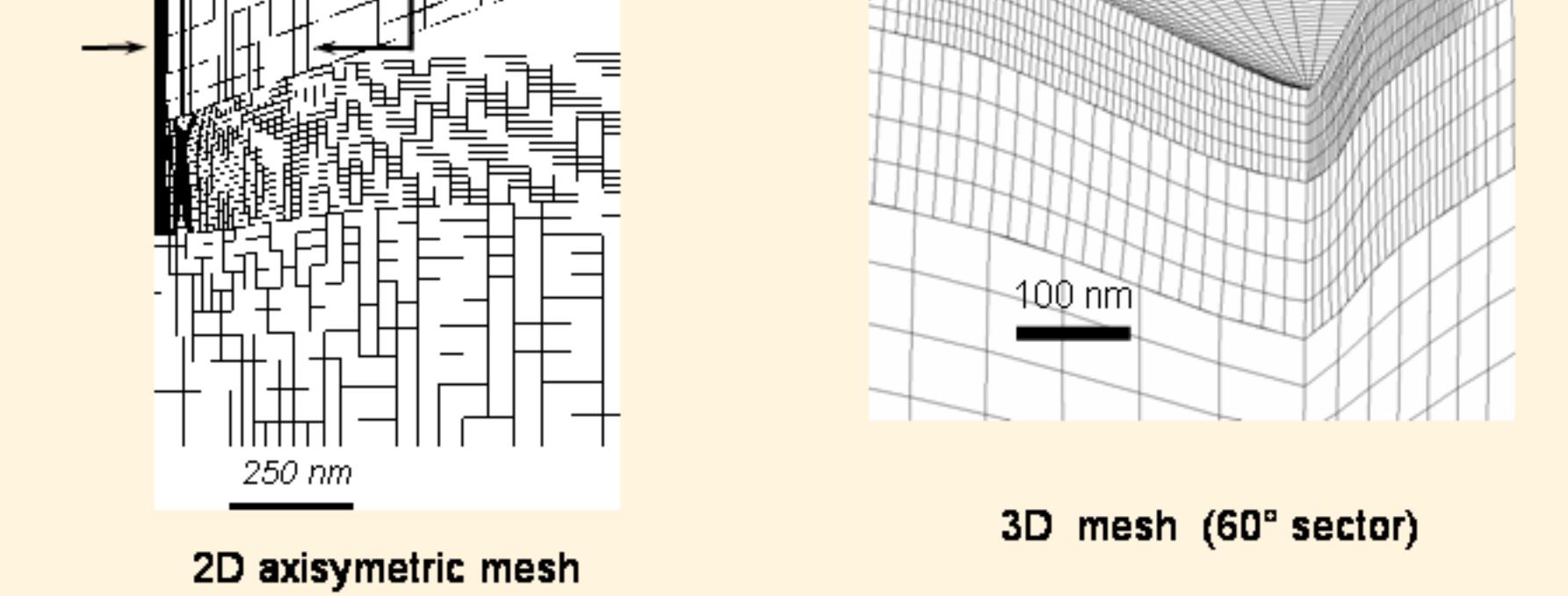
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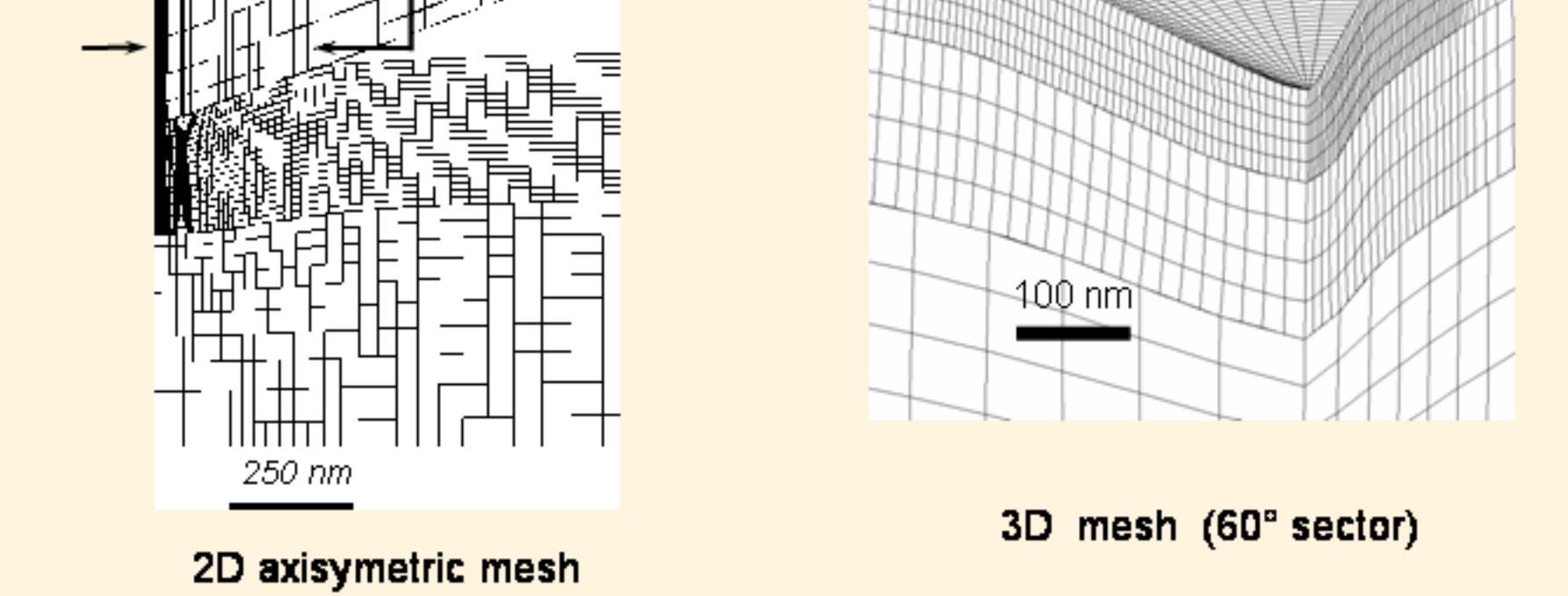
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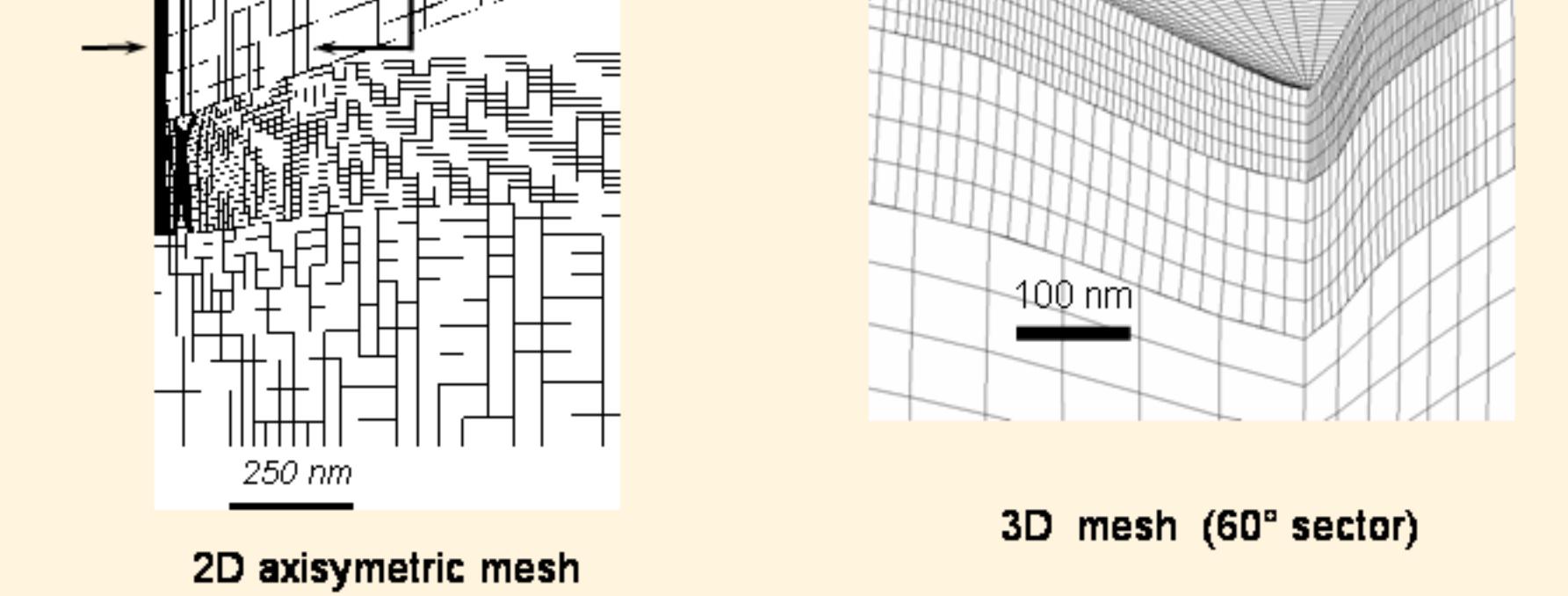
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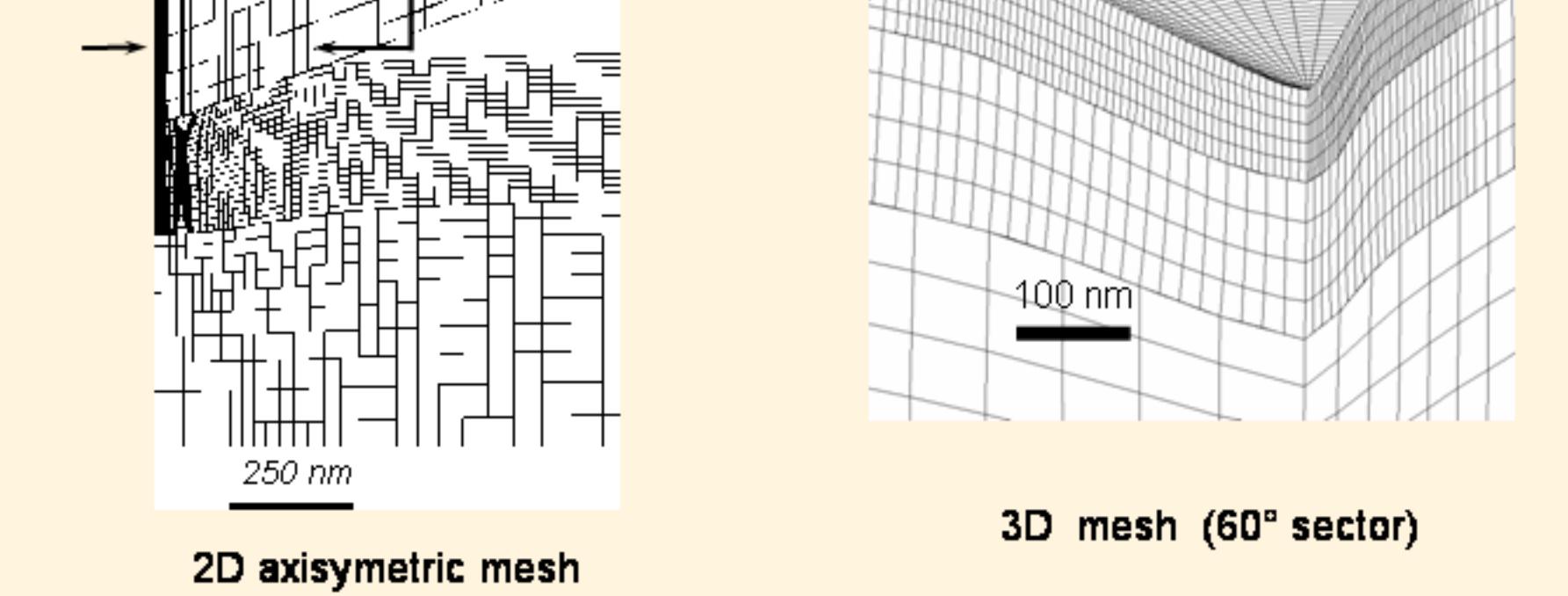
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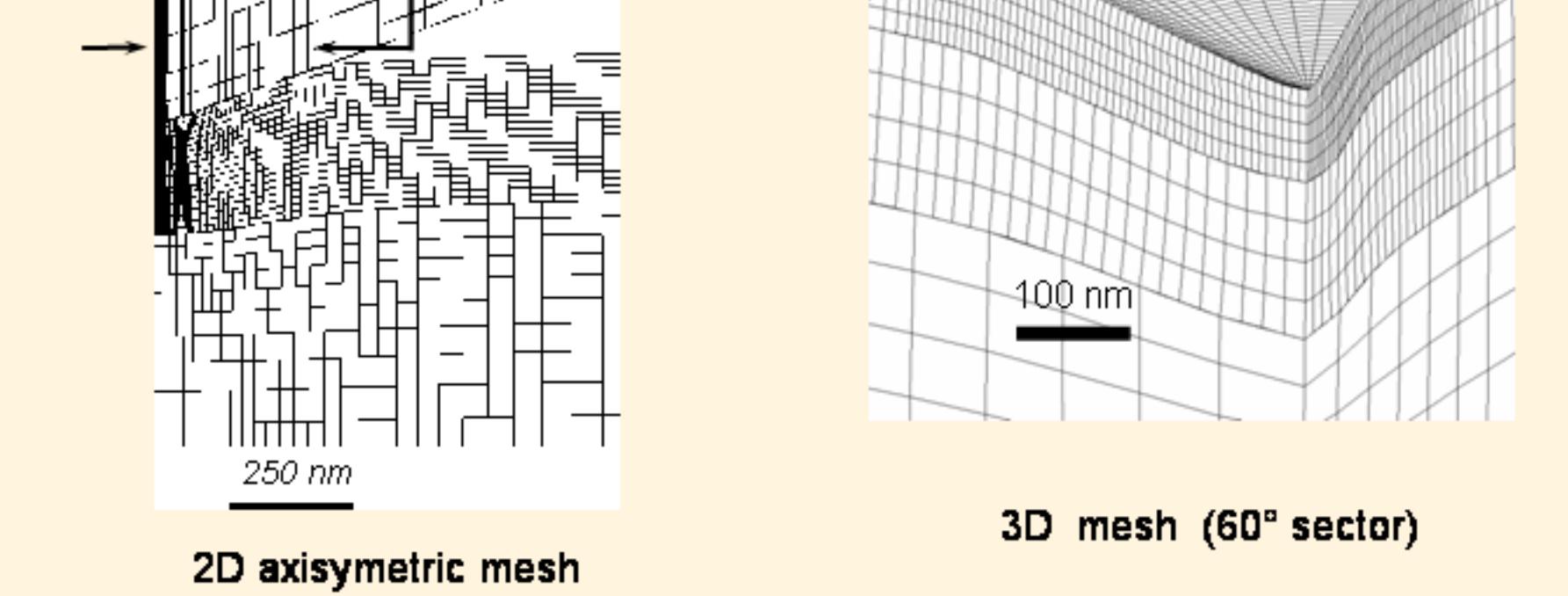
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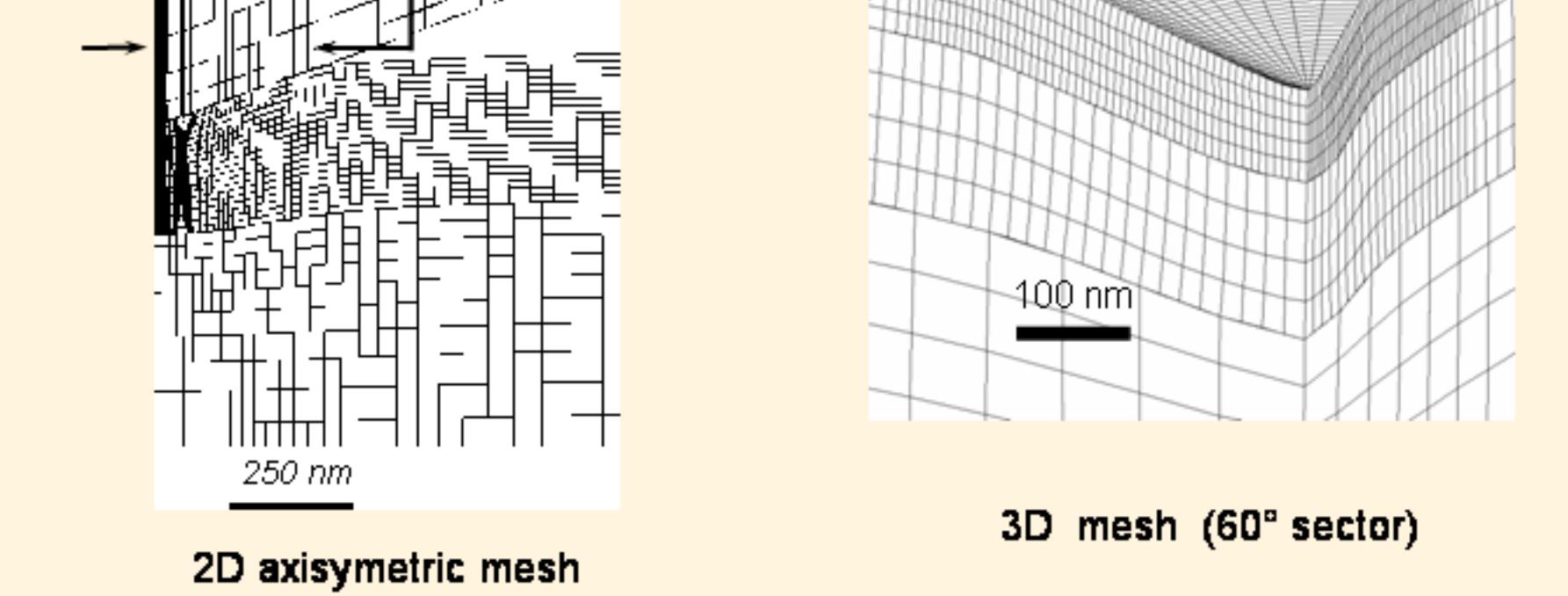
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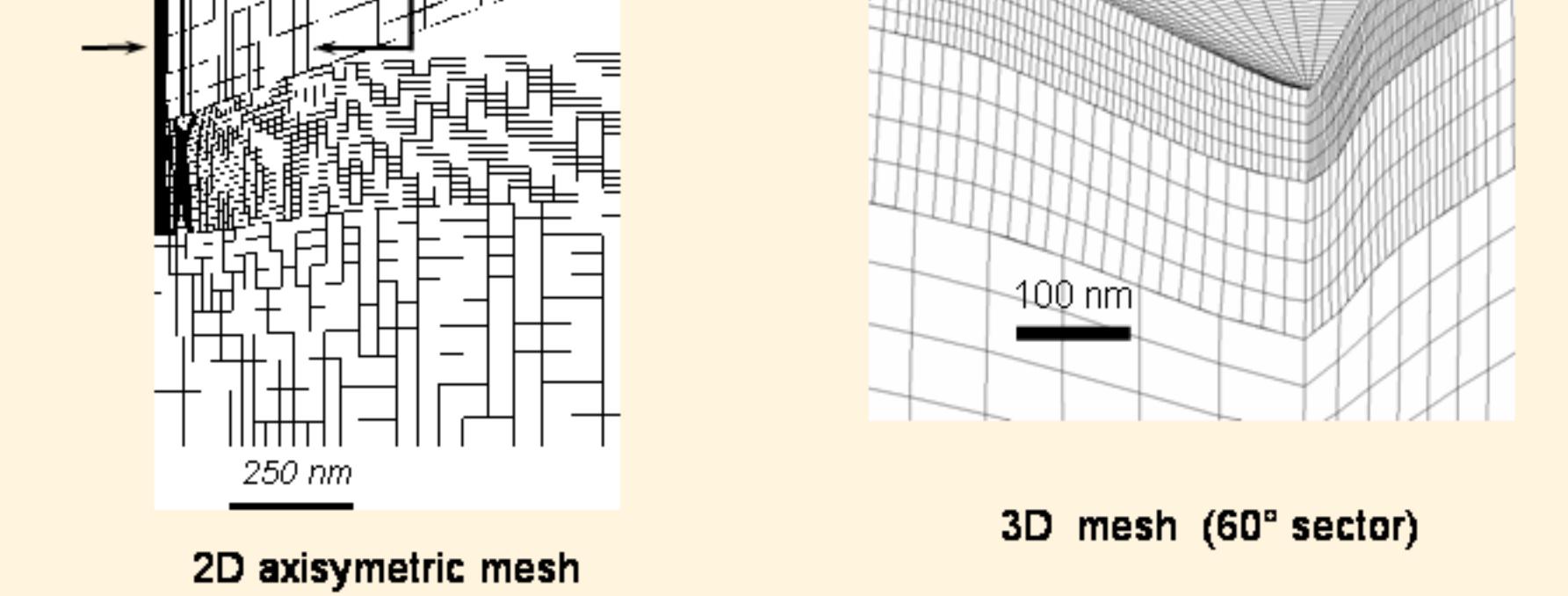
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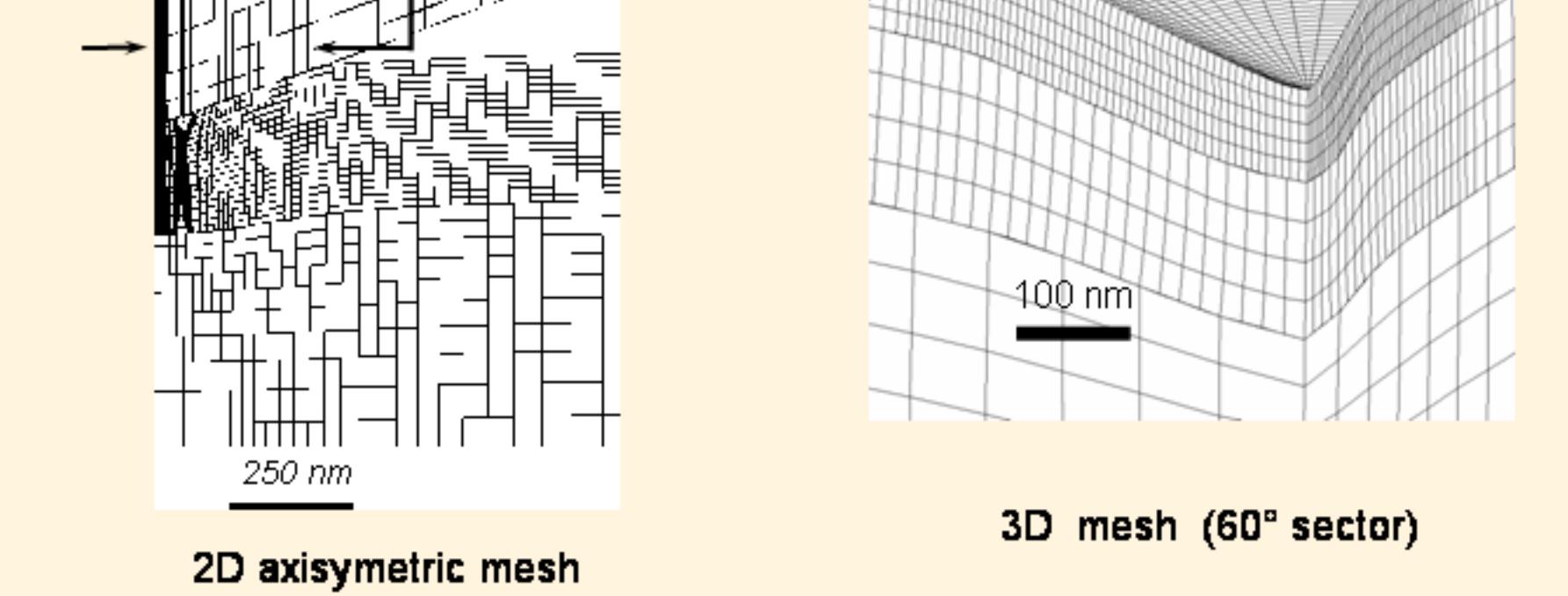
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